DEFINING SOCIAL AND ECOLOGICAL INTERACTIONS IN WEST HAWAIʻI

USING PARTICIPATORY CONCEPTUAL ECOSYSTEM MODELING

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Abstract

Numerous threats compromise the West coast of Hawai‘i Island’s capacity to deliver socially valuable ecosystem services. The problem’s complexity and region’s ecological and economic importance prompted the National Oceanic and Atmospheric Administration to initiate an Integrated Ecosystem Assessment (IEA), a program focused on conducting scientific research to support ecosystem-based management. Initial IEA phases characterize the ecosystem and identify monitoring indicators. Participatory workshops involving managers, scientists, and community members gathered place-based knowledge to develop conceptual ecosystem models (CEMs) guided by the Driver-Pressure-State-Impact-Response framework. Generated CEMs represent ecosystem state components (corals, reef fishes, pelagic fishes, and water body), biophysical and anthropogenic threats, and ecosystem services, as well as the interactions between these attributes. CEMs identify the strongest perceived ecosystem pressures, and impacted ecosystem components and services. Identified indicators suggest key ecosystem attributes are not currently monitored. CEM development is an important phase of the IEA, informing future research and prioritizing management decisions.

Table of Contents

List of Tables

List of Figures

Introduction

In Hawai‘i, coral reefs provide numerous goods and services to society, including but not limited to food, recreation, coastal protection, educational purposes, medicinal purposes, cultural value, aesthetic value, and substantial economic value (Cesar and Van Beukering, 2004; Friedlander et al., 2008). Residents and tourists alike depend on on coral reefs for these services. Tourism statewide largely relies on Hawai‘i's coral reefs; the vast majority of tourists participate in marine based recreation while visiting Hawai‘i (Cesar and Van Beukering, 2004; Hawaii Department of Business Economic Development and Tourism, 2015). Society's reliance on reefs makes their recent declines all the more worrisome.

Over the past two decades, the condition of coral reefs in Hawai‘i has deteriorated (Friedlander et al., 2008). Threats to marine ecosystems, particularly coral reefs, include climate change, coral disease, land development, pollution, runoff, marine debris, and damaging forms of recreation (such as trampling of reefs) (Friedlander et al., 2008; State of Hawaii, 2010). Moreover, society is inseparable from marine ecosystems (McLeod and Leslie, 2009); society both impacts and depends on resources that are generated through complex system interactions (Ostrom, 2009). These interactions create a coupled social-ecological system.

The temporally and contextually fluid connections between society and marine systems are fundamental to our basic understanding of the social-ecological system dynamics. Effective management is based on a thorough understanding of the social-ecological system (Elliott, 2002; Loomis et al., 2014; Samhouri et al., 2014). Marine systems benefit from management strategies developed through multi-stakeholder collaborations that take both sides of the system into account (Fletcher et al., 2014; Hughes et al., 2005; Nuttle and Fletcher, 2013). However, most studies of coral reef social-ecological systems do an inadequate job of describing the links between society and ecological conditions (Kittinger et al., 2012) and ignoring society equates to ignoring a large part of the problem (Samhouri et al., 2014).

Ecosystem-Based Management of Social-Ecological Systems and Ecosystem Services

Ecosystem-based management (EBM) is an approach to resource management that broadens focus to an entire ecosystem, including society and human wellbeing (Atkins et al., 2011; Breslow et al., in press; Kelble et al., 2013). EBM specifically links actions of society, such as land development and economic expansion, with the ecological system, and puts this relationship at the core of its methods (McLeod and Leslie, 2009). This ecosystem-oriented focus contrasts with initial strategies that emphasized close management or monitoring of one species or aspect of an ecosystem (Elliott, 2002; Hohenthal et al., 2015; Kelble et al., 2013). United States Executive Order (EO) 13547 (2010) called for coastal and marine management to incorporate ecosystem-based methods (Obama, 2010) and move away from single sector management. The EO was motivated by evidence that a single sector or species focus was ineffective, in part because it disregards cumulative impacts that occur when multiple human activities interact (Halpern et al., 2008; Kelble et al., 2013; McLeod and Leslie, 2009; Samhouri et al., 2014).

A key aim of EBM is to understand how societal actions ultimately influence the multiple benefits that ecosystems supply to society (Levin et al., 2009; McLeod and Leslie, 2009). These socially valuable benefits derive from ecological processes, and are called ecosystem goods and services (often shortened to ecosystem services) (Guerry et al., 2012; Kelble et al., 2013; Millennium Ecosystem Assessment (MEA), 2005; Potschin and Haines-Young, 2011). Ecosystem services can be divided into four categories: (1) provisioning: the material or energy outputs from an ecosystem (e.g., food, freshwater, and medicinal resources; often referred to as "goods"), (2) regulating: services provided by ecosystem processes (e.g., coastal protection, water filtration), (3) supporting: services required to sustain the existence of other ecosystem services (e.g., habitat and genetic diversity), and (4) cultural services: non-material benefits obtained from ecosystem (e.g., cultural value, education, and existence of a place) (Millennium Ecosystem Assessment (MEA), 2005; TEEB, 2010). Ecosystem services can decrease when the delivering ecosystem state degrades (Nuttle and Fletcher, 2013). Incorporating ecosystem services into decision making is critical because these services greatly contribute to human well-being, yet are currently not widely accounted for in management strategies (Boyd and Banzhaf, 2007). To do so requires an understanding of the relationships within a social-ecological system that both produce and limit socially valuable ecosystem services (Potschin and Haines-Young, 2011).

Beyond incorporating ecosystem services, another primary element of EBM lies in the process; building a systems understanding encompassing social dependencies and system structure requires collaboration across resource managers, users, and scientists. Including ecosystems and associated social dynamics in a management strategy requires multiple sectors to collaborate and share knowledge (McLeod and Leslie, 2009). This collaboration benefits stakeholders by creating an opportunity to uncover parallel goals and evaluate trade-offs between multiple management objectives (Levin et al., 2009), even if it can be a difficult process to facilitate (Leslie and McLeod, 2007).

Some movement towards EBM is evident in the state of Hawaiʻi. Most coastal resource managers in the state (80% of 57 interviewed by (Carrier et al., 2012)) identified whole ecosystems and cultural resources within their management responsibility (Carrier et al., 2012). West Hawaiʻi has begun creating Marine Managed Areas (MMAs) to regulate fishing as well as incorporating community managed areas (e.g., Miloliʻi became a Community Based Subsistence Fishery Area in 1995; Tissot et al., 2009). While the EBM concept is accepted by many scientists and resource policy experts in Hawaiʻi and elsewhere, transition away from managing single resources or activities has been slow (McLeod et al., 2005). Implementation of EBM is difficult without a structured framework that can translate concept into action (Espinosa-Romero et al., 2011). Specific methodology and examples of successful implementation are largely lacking (Cowling et al., 2008; deReynier et al., 2010; Leslie and McLeod, 2007; Tallis et al., 2010). Furthermore, once an ecosystem-based strategy is implemented, monitoring and adaptation of the strategy is required to ensure that it adapts to changing regional conditions and achieves stated goals (Leslie and McLeod, 2007). These challenges can be addressed by incorporating a framework rooted in EBM that provides guidance for procedure and implementation (Tallis et al., 2010).

Using the West Hawaiʻi Integrated Ecosystem Assessment to Implement EBM

The National Oceanic and Atmospheric Administration (NOAA) responded to the national mandate to conduct EBM by initiating a new program called an Integrated Ecosystem Assessment (IEA) (Levin et al., 2009). The IEA program currently takes place in five locations: Alaska, the Great Lakes, the Northeast Shelf, the Gulf of Mexico, California, and Hawaiʻi (Samhouri et al., 2014). The IEA implements EBM by providing a structured format for selecting management actions that encompass social and ecological aspects of the ecosystem (Samhouri et al., 2014). The structured format begins by developing a comprehensive assessment of the region (described in depth below as the scoping process) to understand current status, and discover what management strategies, policies, or objectives contribute to the improvement of this status (Levin et al., 2008). These goals are addressed in part through participatory methods involving experts, managers, and community members (deReynier et al., 2010).

NOAA selected the west coast of Hawaiʻi Island (West Hawaiʻi) as an IEA location due to the region's dynamic ecology, high species diversity, existing quantitative ecological data, and the diversified social activities that rely on the ecosystem (e.g., tourism, aquaculture, agriculture, fishing) (National Oceanic and Atmospheric Administration, 2016). (See Study Site section in Methods, below, for more detail on the West Hawaiʻi region.) A primary goal of the West Hawaiʻi IEA is to understand how human activities affect ecosystem processes, which in turn affects human well-being, and to use this understanding to improve management (National Oceanic and Atmospheric Administration, 2016).

The IEA lays out an iterative process that begins with a scoping phase involving multiple stakeholders who collectively define 1) the biophysical and socio-economic drivers and pressures of the ecosystem and 2) management goals and objectives for the ecosystem (Espinosa-Romero et al., 2011; Levin et al., 2009; Levin et al., 2014; Tallis et al., 2010). The inclusion of multiple stakeholders in the scoping phase is critical to the IEA, particularly in marine ecosystems, because it is common that management issues cross social, ecological, and/or political boundaries and resource user groups (e.g., fishermen, tourists, farmers) (Levin et al., 2009). During this collaborative stage, qualitative conceptual models describing change within the social-ecological system can be constructed (Tallis et al., 2010). Multiple events, such as workshops or presentations, can be held to support the construction of these models (Samhouri et al., 2014).

The second part of the IEA process consists of stakeholders selecting indicators to measure and monitor ecosystem attributes identified during the scoping phase (Levin et al., 2014). Indicators represent biophysical or social states of the ecosystem that can be monitored to assess status and changes (e.g., ocean temperature, fish biomass, number of tourists visiting a reef per year) (Espinosa-Romero et al., 2011; Levin et al., 2009; Levin and Möllmann, 2015). These indicators can measure movement towards unfavorable ecosystem state conditions via naturally occurring or anthropogenic influences (Levin et al., 2009). Indicator thresholds clarify high-risk areas within the ecosystem, and inform future stages of the IEA; this includes monitoring, evaluation, and adaptation of these high-risk areas (Espinosa-Romero et al., 2011; Levin et al., 2009). Indicators that measure biophysical aspects of the ecosystem are common, but measuring the social pieces is less common (Samhouri et al., 2014). Qualitative data collection (e.g., workshops) is a valuable method for selecting indicators of social wellbeing (Breslow et al., in press).

The subsequent stages of the IEA involve and assessment and risk analysis of the region, evaluation of management strategies, ecosystem monitoring, and any necessary adaptation to management strategies (Levin et al., 2009). This research directly supports West Hawai‘i IEA's scoping and indicator stages and develops comprehensive systems models and identifies locally relevant monitoring indicators.

Conceptual Ecosystem Modeling to Support and Facilitate the IEA

A comprehensive understanding of the social-ecological system is the foundation of an IEA (Kelble et al., 2013). Conceptual models are effective educational tools that aid in representing knowledge (Elliott, 2002; Novak and Canas, 2008), therefore other IEAs have used them to discover, comprehend, and communicate relationships that exist among the habitats, species, and social aspects of a system (Harvey et al., in press; Samhouri et al., 2014). A conceptual model brings together and displays multiple concepts, defined as a pattern or event, and summarizes the relationships among them (Elliott, 2002; Novak and Canas, 2008).

Conceptual Ecosystem Models (CEMs) diagram social-ecological system components (i.e., natural or anthropogenic events or processes) and the relationships between these components (Kelble et al., 2013). CEMs illustrate an understanding of system dynamics, key processes, and the relationships between ecosystem components, as well as highlight social influence and values (Gross, 2003; Kelble et al., 2013). In turn, CEMs, as a whole, display a working hypothesis about a system's form and function (Manley et al., 2000).

CEMs help merge existing scientific and community knowledge (Kelble et al., 2013) by collecting information and observations. Collecting place-based knowledge from community members is an effective way to gather information on local areas and resource use, particularly in collecting nuanced or conditional details (Levine and Feinholz, 2015). CEMs effectively synthesize qualitative data, which is especially important when quantitative data are scarce for any part of the social-ecological system (Hohenthal et al., 2015). Qualitative data also provide a rich understanding of human dimension ecosystem services that would be difficult to measure through quantitative data (e.g., cultural practices or sense of place) (Breslow et al., in press). Recent developments of CEMs included collaboration between scientists, managers, and community members to understand the structure and function of their social-ecological system (Levin et al., 2014; Svarstad et al., 2008; Yee et al., 2014). This participatory process can develop relationships between diverse social groups, which enhances communication and relationships (Levine and Feinholz, 2015).

A completed CEM can identify gaps in existing knowledge, facilitate the designation of ecosystem monitoring indicators, and aid in creating adaptive management strategies (Manley et al., 2000; Nuttle and Fletcher, 2013; Ogden et al., 2005). Kelble et al. (2013) posits that CEMs, and the process of developing them, can integrate knowledge across multiple disciplines and qualitatively categorize components of the ecosystem in a manner that captures existing drivers and pressures (Kelble et al., 2013). Kelble et al. also assert that a CEM will represent an accurate consensus of ecosystem function, including how society impacts and relies upon all components, and will identify ecosystem monitoring indicators for the system (Kelble et al., 2013). A completed CEM may also serve as the first step in in developing quantitative or numerical models (Elliott, 2002).

The CEM methodology is not without its limitations. The process of constructing CEMs relies heavily on the input of expert and local knowledge, and acquiring participation can be difficult. Models also represent a generalization of the system, and may leave out currently unknown or unaddressed components (Gross, 2003). Despite limitations, CEMs are a good choice for characterizing the West Hawai‘i social-ecological system. They successfully capture a diverse knowledge base to create a consensus of the system (Harvey et al., in press). This is especially important in West Hawai‘i, where the IEA has a strong focus on generating participation among multiple stakeholders.

Using a Structured Framework to Support Development of Conceptual Ecosystem Models

The CEMs developed in this research follow the Driver-Pressure-State-Impact-Response (DPSIR) framework (*Figure 1*). Other IEA regions use the DPSIR framework, and other studies used it to guide conceptual model development (Kelble et al., 2013; Levin et al., 2008; Samhouri et al., 2014; Yee et al., 2014). The DPSIR framework organizes an ecosystem in a cause-and-effect manner to define key social and ecological components and interactions (Binder et al., 2013; Gari et al., 2015; Organization For Economic Cooperation And Development, 1993; Smith et al., 2016). DPSIR-based CEMs can then communicate these social and ecological relationships to resource managers and community members (Smith et al., 2016). With extension, the framework is also a valuable tool for measuring the intensity of those relationships (Cook et al., 2013; Gari et al., 2015; Reiter et al., 2013).

The DPSIR framework first originated as the Stress-Response framework, developed by Statistics Canada (Friend and Rapport, 1991). The Organization of Economic Co-operation and Development (OECD) expanded this to the Pressure-State-Response framework in 1993, and the European Environmental Agency (EEA) further developed it in 1999 to Driving Force-Pressure-State-Impact-Response framework (Gari et al., 2015; Jago-on et al., 2009; Sekovski et al., 2012). The additions the EEA added to the framework linked societal action and associated ecosystems (Lewison et al., 2016). The DPSIR has since been used in a multitude of studies (Sekovski et al., 2012) leading to many variations of the DPSIR framework (e.g., Atkins et al., 2011; Hohenthal et al., 2015; Kelble et al., 2013; Yee et al., 2014). Modifications to the framework include incorporating ecosystem services (e.g., Kelble et al., 2013) and creating additional variables in the framework intended to include historical information and tangible societal actions (e.g., Hohenthal et al., 2015).

In a recent review of DPSIR methodology and applications globally, Gari et al., (2015) concluded that determining clear definitions for concepts and terminology is critical to successful application. As illustrated in Figure 1, I define drivers as the natural or anthropogenic forces (e.g., ocean dynamics or agriculture) that cause a change in the level of a pressure (e.g., nutrient input or habitat destruction). Drivers can be further classified as distal (e.g., global climate change) or proximal (e.g., local climate) (Kittinger et al., 2012). The pressures then act as the direct cause of a change to the ecosystem state (Smith et al., 2016). This change impacts the services, benefits, and associated values (e.g., food, recreation, or aesthetic value) that society receives from that particular ecosystem (Potschin and Haines-Young, 2011). In response to these changes, society can act at any level (driver, pressure, state, or impact) to leverage improvement.

Applying the DPSIR framework to this research requires addressing limitations of the framework. Gari et al. (2015) presents criticisms from multiple studies which state that the simplified manner in which relationships are represented, and the absence of feedbacks, creates a falsely linear model that does not capture complexities that are known to be present in reality. The DPSIR framework does not account for simultaneously occurring relationships (Gari et al., 2015) or differences in intensity or scale of pressure to state relationships (Smith et al., 2016). To address these criticisms requires ensuring relationships are well defined. It also may require labeling relationships with high levels of uncertainty.

Identifying the social and ecological drivers and pressures within a system is an essential portion of any IEA (Levin and Möllmann, 2015). Creating CEMs based on DPSIR builds an organized representation of the marine ecosystem in a cause-and-effect structure (**Figure 2**) (Gari et al., 2015; Yee et al., 2014). The DPSIR framework is valuable in its ability to assist in identifying relationships within the social-ecological system, and provide the opportunity for discourse regarding management issues related to these relationships (Lewison et al., 2016). A DPSIR-based CEM translates scientific and place-based knowledge to stakeholders, which can advise management strategies aiming to reduce the impact that society has on an ecological system (Atkins et al., 2011; Binder et al., 2013).

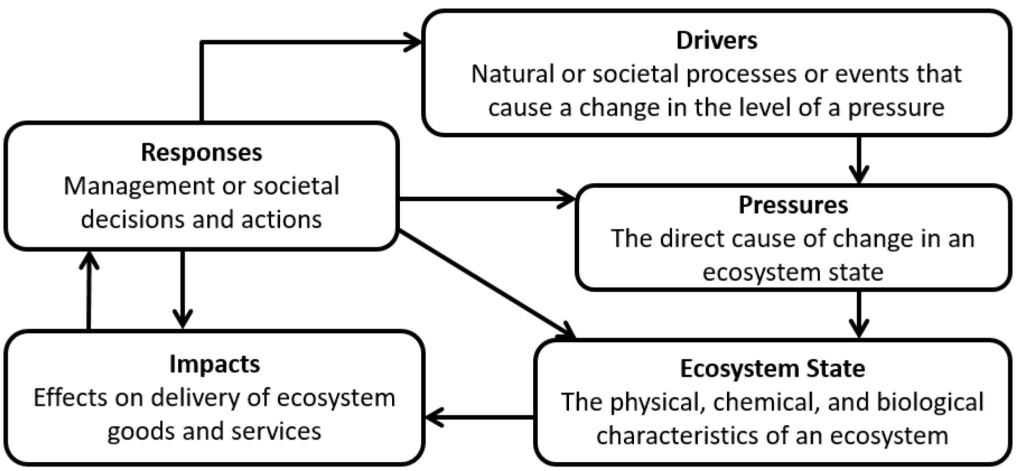

Figure 1: A diagram of the Driver-Pressure-State-Impact-Response framework. Arrows represent movement between levels. Response arrows are directed to all levels, since responses may be directed toward any or multiple levels. Adapted from Hohenthal et al., 2015; Yee et al., 2015; Kelble et al., 2013.

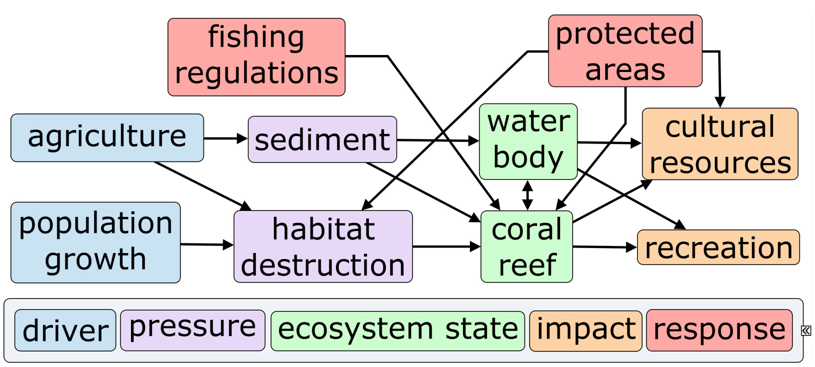

Figure 2: Simplified and hypothetical example of a Conceptual Ecosystem Model for a social-ecological system, using the Driver-Pressure-State-Impact-Response framework. Adapted from Hohenthal et al., 2015; Yee et al., 2015; Kelble et al., 2013.

Aim & Significance

The overarching goals of my research were to support EBM in West Hawaiʻi, evaluate the local perceptions of threats to the marine ecosystem, and understand how these threats impact human well-being via changes in ecosystem services. Successful resource management that addresses the entire social-ecological system requires collaboration between management entities, scientists, and community members. It must capture local and place-based knowledge to examine social and ecological interactions. Specifically, my research aims to create CEMs that improve the understanding of the region's drivers and pressures, locally relevant ecosystem monitoring indicators, and existing ecosystem services. To accomplish this, my methods included participatory workshops and surveys that asked a diverse group of people to define the interacting ecological, biophysical, cultural, and economic components of the region. With the qualitative data collected, I conceptually modeled existing reciprocal relationships in West Hawaiʻi. My research also began to quantify the relative strength of identified system relationships to determine which locally perceived interactions are the strongest, and thus potentially are priorities for management. Finally, I examined whether these strongest interactions are being measured through an analysis of ecosystem monitoring indicators.

Research Questions

1. What are the locally perceived socio-economic and biophysical drivers causing pressures within West Hawaiʻi's marine ecosystem, how do these pressures affect the state of the ecosystem, and what are the implications for ecosystem services?
2. How can the DPSIR-CEM participatory process inform and support management in West Hawaiʻi?

Methods

Approval to Conduct Research with Human Subjects

Participatory methods involving managers, scientists, and community members gathered qualitative data that CEMs. Participants provided input through group discussions, activities, and surveys. The University of Hawaiʻi's Human Studies Program deemed this research exempt from federal regulations pertaining to the protection of human research participants (CHS #23155).

Study Site

The Natural and Social Systems

Hawai‘i Island has 428 km of coastline (Hawaii Department of Business Economic Development and Tourism, 2015); the west coast is approximately 230 km in length. On Hawai‘i Island, 219 km^2 are classified by the State of Hawaii as urban landscape, 5278 km^2 are conservation, 4908 km^2 are agriculture, and 8 km^2 are rural (Hawaii Department of Business Economic Development and Tourism, 2015). The three major ecosystems found in West Hawai‘i are tropical wet forest, tropical dry forest, and tropical grassland and shrubland (The Nature Conservancy, 2016).

In 2015, the population of Hawai‘i Island was 196,428 people (Hawaii Department of Business Economic Development and Tourism, 2015). This is in contrast to 61,332 people in 1960, a 320% increase in 55 years (Hawaii Department of Business Economic Development and Tourism, 2015). The population is expected to reach 220,900 people by 2020, which would be a 112% increase from the 2015 population (Department of Business, 2012).

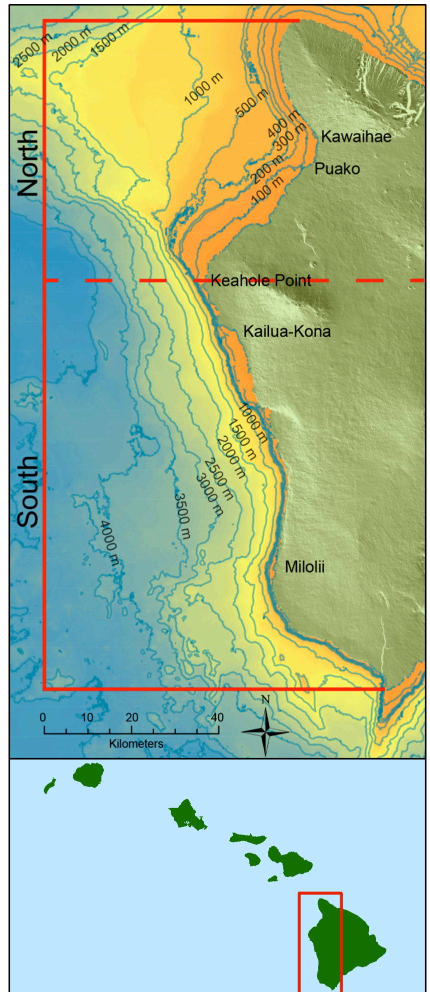

Figure 3: Bathymetric map of West Hawai‘i Island. Red lines dictate division of North and South region used in this research. Map data from Hawai‘i Mapping Research Group, UH Mānoa.

West Hawai‘i has the largest undamaged and growing coral reef in the Main Hawaiian Islands (Couch et al., 2014; Jokiel et al., 2004). The majority of West Hawai‘i coral reefs have not experienced widespread declines in coral reef abundance, compared to other regions throughout the state that are subject to impacts from a larger population and long-term environmental stressors (e.g., nutrients entering near-shore waters via submarine groundwater; Parsons et al., 2008). However, coral cover is in decline in particular locations in West Hawai‘i (e.g., Puakō, Mauna Lani, Ka’ūpūlehu and Hōnaunau; Minton et al., 2015; Minton et al., 2012; Walsh et al., 2013).

To simplify the complexity of the CEMs constructed in this research, West Hawai‘i is divided into North and South West Hawai‘i (*Figure 3*). The division between North and South is located approximately at Keahole Point, an appropriate division due to physical, ecological, and social differences between the two regions (PIFSC, 2016).

Existing Knowledge About Threats to West Hawaiʻi

Numerous threats to West Hawaiʻi's coral reefs and coastal region exist and include (but are not limited to) climate change, population increase, coastal development, land-based sources of pollution, fishing pressure, and damaging forms of tourism (e.g., habitat destruction, sunscreen pollution, and animal harassment) (Friedlander et al., 2008; State of Hawaii, 2010). Coral cover loss can occur due to sedimentation, coral disease, and other causes (Walsh et al., 2013). Some West Hawaiʻi reefs are experiencing coral cover decline and colony level damage that negatively impacts the overall state of the reef (Couch CS et al., 2014). Ultimately, these threats compromise the ability of the coral reef and coastal environment to produce the multiple ecosystem goods, services, and benefits that society values (Kittinger et al., 2012).

Impacts from a changing climate are already evident across the state of Hawaiʻi, and future global warming will lead to a number of relevant changes. Climate change affects sea surface temperatures, sea level, precipitation, extreme weather events, air temperature and ocean pH levels (Fletcher, 2010). Average annual sea surface temperatures in Hawaiʻi are increasing (Jokiel and Brown, 2004) which can lead to coral bleaching and susceptability to disease. In 2015, the temperature of West Hawaiʻi's coastal waters were unusually high, and many reefs experienced severe bleaching (Rosinski and Walsh, 2016). Moreover, sea level in Kawaihai Harbor in West Hawaiʻi have increased at a rate of 3.79 mm per year (Vitousek et al., 2009).

Annual precipitation levels vary across space in West Hawaiʻi, ranging from 204-2000 mm, with the majority of the region receiving between 204-750 milimeters (Giambelluca et al., 2013). West Hawaiʻi has experienced a decline in mean annual rainfall since the early 1980s, and an increase in the incidence of extreme weather events (Giambelluca et al., 2013). Precipitation influences surface and groundwater hydrology, and is transmitted to the marine environment via surface run-off and base flow (Giambelluca et al., 2013). Certain regions along the West Hawaiʻi coastline receive cold submarine groundwater discharge (specific areas include Kohanaiki area, and Kaloko to Honokōhau) that mixes with surface ocean water and potentially lowers water temperatures in shallow areas (Marrack et al., 2014). It is important to note that deeper waters where corals actually exist may be warmer (Marrack et al., 2014). Submarine groundwater discharge delivers substantial nutrients and contaminants from land-based activities to the marine environment (Oki, 1999). Wiegner et al. (2006) found that coastal development in West Hawaiʻi (specifically the Kohala and North Kona area) is associated with increased nutrients in adjacent marine environments, and coral reefs in this region may be approaching their tolerance level for nutrient concentrations (Wiegner et al., 2006).

Land-based sources of pollution add additional nutrients to the marine environment. The increasing population in West Hawaiʻi has specifically led to an increase in effluent levels, particularly from on-site waste disposal systems (PIFSC, 2016). The state of Hawaiʻi has approximately 110,438 onsite waste disposal systems (Whittier and El-Kadi, 2014). Of these, 58,982 are found on Hawaiʻi Island, and 49,344 of those are cesspools, in which wastewater receives no treatment (United States Environmental Protection Agency, May 2004 Update/HI; Whittier and El-Kadi, 2014). From 1992-2010, the number of onsite waste disposal systems in West Hawaiʻi almost doubled (Whittier and El-Kadi, 2014). Wastewater can contain pathogens, nitrates, and other contaminants that enter groundwater and travel to and negatively influence the marine environment (United States Environmental Protection Agency, May 2004 Update/HI; Whittier and El-Kadi, 2014). The increase in nutrients delivered to the marine environment has resulted in declines in coral cover in West Hawaiʻi reefs (Parsons et al., 2008).

West Hawaiʻi supports a non-commercial and commercial (including aquarium collection) fishery (Walsh, 2014). Reporting non-commercial catch is not mandatory, and both commercial and non-commercial reports underestimate total catch and species composition (Everson and Friedlander, 2004; Kittinger et al., 2015; Zeller et al., 2008). This fishing activity affects total fish biomass. Target fish biomass is greater in areas with restricted fishing pressure as well as in regions adjacent to these regions due to a spillover effect (Stamoulis and Friedlander, 2013). In Ka'ūpūlehu reefs, target fish species have a lower biomass than target fish species in regions that are closed to fishing (Minton et al., 2015). In addition, there was no difference in total biomass found in non-target species (Minton et al., 2015). While other stressors are likely impacting overall fish biomass, the only stressor likely to affect only target fish species is fishing (Minton et al., 2015).

Tourism is Hawaiʻi Island's largest source of economic activity (State of Hawaii's Department of Business Economic Development and Tourism, 2006). Across the state, tourists primarily recreate in marine and near-shore environments (State of Hawaii's Department of Business Economic Development and Tourism, 2006). In 2004, the annual monetary value of coral reefs to the state of Hawaiʻi was estimated to be $360 million, of which $304 million was estimated to be from tourism (Cesar and Van Beukering, 2004). Tourism, while sustaining Hawaiʻi's economy, also presents its own threats to marine environments. In 2015, an estimated 1.5 million visitors came to Hawaiʻi Island, with 1.3 million visitors staying in Kona (Hawaii Department of Business Economic Development and Tourism, 2015). A study in Kealakekua Bay found more broken and bleached coral in areas with high levels of recreational diving (Tissot and Hallacher, 2003). Along with physical habitat destruction, tourism brings high levels of sunscreen pollution that contain chemicals (i.e., oxybenzone) known to negatively impact corals, leading to polyp deformities and bleaching (Downs et al., 2016).

Current Management Efforts

State and federal agencies are in charge of governing marine resources in the main Hawaiian Islands (Tissot et al., 2009). Management all of the state's marine resources is difficult since each location within the state has a different social and political climate (Tissot et al., 2009). In West Hawaiʻi, the Department of Land and Natural Resources' Division of Aquatic Resources (DAR) is charged with managing coastal areas yet lacks funding and staff members (Levine and Feinholz, 2015) which can hinder its ability to create and enforce rules and regulations. In West Hawaiʻi, there are several small non-governmental agencies that play a role in management, including The Nature Conservancy, Malama Kai Foundation, Lost Fish Coalition, and Kula Naia Wild Dolphin Foundation (Tissot et al., 2009). Current management of West Hawaiʻi's marine ecosystem includes community-based management areas and a network of Marine Managed Areas (MMAs), or areas designated by law to conserve and protect marine resources (Ayers and Kittinger, 2014; Tissot et al., 2009). West Hawaiʻi marine environment includes four Marine Life Conservation Districts (MLCD), seven Fisheries Management Areas (FMA), one Bottomfish Restricted Fishing Area (BRFA), and the West Hawaiʻi Regional Fisheries Management Area (WHRMFA; State of Hawaii Division of Aquatic Resources, 2016).

The WHRFMA spans the West Hawaiʻi coastline and prohibits fish feeding, scuba spear fishing, and take of particular species (e.g., species of stingray and reef sharks). The WHRFMA also includes of a network of Fish Replenishment Areas (FRA) and Netting Restricted Areas (NRA), which restrict the take of aquarium fish species and lay net fishing, respectively. In 1998, Hawaiʻi State Legislature created the WHRFMA, largely in response to public concerns regarding an expanding aquarium fishery (Tissot et al., 2004). In 2000, the WHRFMA designated fourteen FRAs and NRAs, encompassing approximately 30% of the coastal waters (Rossiter and Levine, 2014; Tissot et al., 2004). The geographical boundaries of the restricted areas were selected through both ecological data and local knowledge (Rossiter and Levine, 2014; Tissot et al., 2009). Success of these reserves can be seen in adult stocks of yellow tang (*Zebrasoma flavescens*), a commonly collected aquarium species, which are currently higher in reserves and in immediately surrounding areas (Friedlander et al., 2008). In July of 2016, a culmination of efforts strongly driven by the Kaʻūpūlehu Marine Life Advisory Committee, DAR, West Hawaiʻi Fisheries Council, and The Nature Conservancy succeeded in creating legislation that added a marine reserve to the WHRMFA (Board of Land and Natural Resources, 2016). The reserve prohibits all take of aquatic species within a 5.8 km stretch of coastline in Kaʻūpūlehu, extending to twenty fathoms seaward, for a ten year rest period (Board of Land and Natural Resources, 2016). Community members, scientists, and lead managers of marine resources in the region largely supported the legislation, although there was opposition from some community members (Board of Land and Natural Resources, 2016). During the rest period, the DAR will monitor resources and develop a marine management plan alongside the community (Big Island Video News, 2016).

Workshops, Surveys, and Interview

This research was conducted through participatory methods consisting of two workshops, two surveys, and one in-depth interview. Participatory methods have been used in similar studies and other IEAs because of their ability to capture local and place-based knowledge, build partnerships among diverse groups, and encourage active participation in management (Samhouri et al., 2014; Tallis et al., 2010). Participatory workshops facilitate the creation of a consensus of system structure and function (Kelble et al., 2013). Surveys and interviews provide a rich understanding of participant knowledge and perceptions (Shackeroff et al., 2011).

Workshop 1: Symposium of West Hawaiʻi's Marine Environment (September 2014)

The objectives of the first workshop included building a comprehensive list of drivers and pressures within the West Hawaiʻi region, and describing the relationships that exist between these drivers, pressures, and the coral reef ecosystem's state. This workshop also served to strengthen collaboration between resource managers, scientists, and community members who live, work, and study in West Hawaiʻi.

On September 3rd and 4th of 2014, NOAA's Pacific Island Fisheries Science Center held a Symposium on West Hawai'i's Marine Ecosystem in Kailua-Kona. The Symposium was advertised via electronic fliers emailed to private, state, and government institutions in related fields. The final portion of the Symposium consisted of a voluntary workshop. The workshop had thirty-two participants total, including community members from West Hawai'i, and representatives from a wide variety of organizations and institutions. These included NOAA, University of Hawai'i at Mānoa, University of Hawai'i at Hilo, Sea Grant, The Kohala Center, The Nature Conservancy, Farallon Institute, South Kohala Reef Alliance, Dolphin Quest, State of Hawai'i's Department of Aquatic Resources, and The Four Seasons Resort at Hualalai. Many (41%) participants from these institutions were also West Hawai'i community members. Participants self-selected into groups by choosing a geographic region (North or South West Hawai'i) based on their knowledge of West Hawai'i, resulting in two North groups and three South groups.

Each group identified and mapped existing and potential threats to their geographic region and discussed possible ecosystem monitoring indicators (e.g., fish biomass, water quality, hotel capacities). An activity facilitator and a note taker were present in each group to record participant input. The groups received a large map of their focus region (North or South West Hawai'i), a large notepad, markers, and icons to label the map. Each icon had an ecosystem threat, habitat type, or social activity printed on it. Scientists who possess ten or more years of experience studying and working with coral reef ecosystems selected these icons prior to the workshop using their experience and relevant peer-reviewed literature. Blank icons were available for participants to add any elements to the map they believed to be missing. Participants attached icons to the map to describe the context of that general geographical location. In some cases, groups circled the geographical context for particular threats, or identified certain regions as uncertain. Groups assigned a score (1 = low to 10 = high) to each icon, representing the perceived level of negative effect the driver or pressure has on the coral reef ecosystem state. The groups discussed indicators that could best monitor the various interactions identified and potential data sources for those indicators. After the workshop, participants filled out a questionnaire asking for comments and potential sources of valuable data. Group notes and questionnaire answers are summarized in the Symposium Workshop Report (Appendix A).

Qualitative data collected during the first workshop included direct observation, photos, and group notes. I used this data to construct seven CEMs: one CEM per workshop group, resulting in two North and three South CEMs, and one comprehensive CEM for both the North and South region. All CEMs followed the DPSIR framework for organization. I created all CEMs using the Florida Institute for Human and Machine Cognition Cmap Tools software, version 6.04.01, July 24, 2015 (available at http://cmap.ihmc.us). I recorded geographic information, possible data sources, and potential indicators noted by groups separately in the workshop report.

Participants in the activity were encouraged to suggest any threat or circumstance that occurs in the region, and then asked to discuss each one before putting them on the map, in effort to reach agreement. The group activity was designed to result in consensus within individual groups on the regional information presented. None of the group notes indicated any objections to group consensus, nor did I personally observe any type of disagreement among groups.

To assemble each CEM, identified threats were classified as distal and proximate drivers according to a framework for coral reef social-ecological systems (Kittinger et al., 2012). Distal drivers were separated into biophysical (e.g., wave forcing and volcanic activity) or socio-economic (e.g., population growth and land development) categories. The icons that participants connected to these identified drivers were labeled as pressures. The pressures connected to the coral reefs off the coast of West Hawaiʻi. Groups were not explicitly asked to identify specific components of the ecosystem or ecosystem services, however some were mentioned (turtles and cetaceans as ecosystem components, and fish, cultural resources, and recreation as ecosystem services). Following concept mapping procedures, I categorized each icon used in the mapping activity as a distal driver, proximal driver, pressure, ecosystem component, or ecosystem service and entered each one into the Cmaps Tools Software. I created visual representations between relationships by connecting them with arrows to depict the direction of the relationship.

I compiled each driver, pressure, and ecosystem service identified in the group level CEMs and created two regional CEMs. To simplify the compiled North and South CEMs, highly specific threats were subsumed into broader driver or pressure categories (e.g., “cattle production” was converted to “animal production”). These constructed North and South CEMs represent the current working hypothesis about the structure of this system, including interactions between biophysical, ecological, and social actions, which may omit currently unknown factors.

CEMs in this research are purposefully not statistically significant representations of the data collected because it would not be appropriate to conduct statistical analyses on these data. CEMs are intended to represent expert and local knowledge.

Workshop 2: Hawaiʻi Conservation Conference (August 2015)

The objectives of the second workshop were to determine how drivers and pressures affect the multiple components of ecosystem state, and how changes in ecosystem state impact the ecosystem services provided to the human community of West Hawaiʻi.

Prior to conducting the second workshop, I constructed a list of relevant components of the ecosystem and ecosystem services using similar studies as reference (Cook et al., 2013; Kelble et al., 2013; Yee et al., 2014). The studies referenced follow the DPSIR framework, and some took place in coastal and marine ecosystems. Before the workshop, a NOAA scientist working with the West Hawaiʻi IEA determined the relevance of both lists in regards to West Hawaiʻi coastal and marine ecosystems. Both lists were intended to be exhaustive, however participants in the workshop were invited to verify and edit them.

On August 3rd, 2015, I hosted a workshop at the Hawaiʻi Conservation Conference (HCC), held at the University of Hawaiʻi at Hilo, Hawaiʻi. The workshop, entitled "West Hawaiʻi Integrated Ecosystem Assessment: Building Partnerships to Support Science and Management of West Hawaiʻi's Marine Ecosystem," had four primary objectives. The first was to verify the previously created lists of drivers and pressures (created at the Symposium workshop), ecosystem components, and ecosystem services with experts and community members. The next objective was to collect information that I would later use to create Ecosystem State CEMs for corals and hard-bottom, reef fishes, pelagic fishes, and the water body. These Ecosystem State CEMs identified which pressures cause a change in the state of the ecosystem component, which drivers interact with those associated pressures, and what ecosystem services were affected by those interactions. Next, participants identified which indicators could monitor the identified interactions. The final objective was to determine the relative intensity of all identified interactions.

In preparation for the workshop, I identified eight components of West Hawaiʻi's coastal and marine ecosystem which collectively comprise its overall structure (Nuttle and Fletcher, 2013). These models, called Ecosystem State CEMs, allow a closer look at how individual components of the ecosystem react to varying drivers and pressures, and how each serves society through the delivery of ecosystem services. The list of components of the ecosystem for West Hawaiʻi consisted of coral and hard-bottom, pelagic fishes, reef fishes, the water body, beaches, anchialine ponds, turtles, and cetaceans. From this list, four were chosen for the workshop: corals and hard-bottom, reef fishes, pelagic fishes, and the water body. These four were chosen based on the participant expertise anticipated to be present at the workshop.

The HCC website advertised the workshop as part of the workshops and trainings available to participants of the conference. An email advertisement also invited participants of the first workshop, and any other potentially interested parties whose contact information was known by the lead scientist of the West Hawaiʻi IEA. Twenty-four participants attended the workshop with a wide range of affiliations; these included NOAA, United States Department of Land and Natural Resources, United States Department of Aquatic Resources, Kaloko-Honokohau National Historic Park, University of Hawaiʻi Sea Grant, Conservation International Hawaiʻi, The Nature Conservancy, Coral Reef Alliance, Puako Community Association, Kihei Charter School, Oahu Army Natural Resources Program, Hanalei Watershed Hui, University of Hawaiʻi at Hilo students, University of Hawaiʻi at Mānoa students, and community members. The workshop was three hours long. It began with a brief introductory presentation about this research, the DPSIR framework, and an explanation of the activity that would be taking place that day. The duration of the activity was approximately 2.5 hours.

The first activity divided participants into four groups based on a component of the ecosystem: corals and hard-bottom, reef fishes, pelagic fishes, and the water body. Participants joined one group based on their knowledge base and expertise; resulting in four people in the water body group, six people in the corals and hard-bottom group, and seven people in both the reef and pelagic fishes groups. The groups each worked with two large posters that listed the drivers and pressures identified in the previous workshop (20 drivers total, 24 pressures total), the ecosystem component, and the list of ecosystem services. On the posters, groups drew an arrow from any pressure that interacts with (i.e., affects) the ecosystem component. Participants then were instructed to choose 2-4 pressures deemed to have the greatest effect or influence on the ecosystem component of focus, and draw arrows from relevant drivers to those pressures. Lastly, groups drew arrows from the ecosystem component to the ecosystem services it impacts.

The next activity quantified the relative strength of identified interactions between selected drivers, pressures, ecosystem components, and ecosystem services (based on the methodology of Altman et al., 2011 and Cook et al., 2014). Groups measured the strength of a driver on a pressure, a pressure on an ecosystem component, or an ecosystem component on an ecosystem service by answering two questions for each interaction (i.e., each arrow drawn):

1. On a scale of 0 (no effect) to 5 (strongest effect), what is the direct effect of X (representing a driver, pressure, or ecosystem component) on Y (representing a corresponding pressure, ecosystem component, or ecosystem service)?
2. On a scale of 1-100%, what proportion of Y is directly affected by X?

Using identified interaction strengths I calculated the cumulative effect of each pressure by summing the strengths of an individual pressure across all ecosystem components. I calculated the cumulative impact to each ecosystem component by summing all pressure strengths to an individual ecosystem component.

In the last activity, groups determined where indicators could monitor identified interactions (e.g., the indicator, total fish abundance, could be used to monitor the extraction of fish pressure onto reef fishes). Groups reviewed a list of ecosystem monitoring indicators created by NOAA scientists, and could add additional indicators to the list if necessary. Groups used Post-It notes to label interactions drawn on their posters with potential indicators. The result was a collection of potential ecosystem monitoring indicators for specific relationships identified in the first activity.

I collected data from this workshop through group notes, photos, and the activity posters. I used the data collected to build four Ecosystem State CEMs (one for corals and hard-bottom, reef fishes, pelagic fishes, and the water body). I followed the same methods used to create the North and South CEMs. I entered each driver, pressure, ecosystem component, and ecosystem service identified on posters in the Cmap Tools software. Once entered, I connected the components with arrows to depict the direction of the relationship, and added associated intensity scores to each arrow as a note.

Survey 1: Value of Participatory Process to Community and Management (August 2015)

During the last 15 minutes of the HCC workshop, participants received a printed copy of an optional anonymous survey. The objective of this survey was to assess whether the participatory aspects of this research hold value for resource managers and community members in West Hawaiʻi. The survey also provided an opportunity for workshop participants to identify any information not collected during the activity.

The survey assessed how participants reacted to the participatory process, if they learned anything from the workshop activity, and if they anticipated they would make changes to their own behavior due to something they gained from being a part of the workshop. The survey asked participants to rank their agreements to statements on a scale of 1 (not at all) to 10 (very much).

Participants wrote in space provided on the printed survey any examples or any additional comments. I transcribed these responses, and calculated the mean and mode of each question. Transcriptions are in the HCC Workshop Report (Appendix B).

Survey 2: Electronic Completion of Relationships (May 2016)

The objective of this survey was to fill the gaps remaining in the Ecosystem State CEMs. Due to time constraints, interactions were not identified in full during the HCC workshop. This survey functioned to completely define all driver-to-pressure interactions, interactions among ecosystem components, and their relationship to ecosystem service.

Participants at the HCC workshop defined interactions for ecosystem services listed. However, I added additional cultural services to the list after the HCC workshop due to participant feedback, personal observation of the activity, and further literature review (Maynard et al., 2010).

I electronically distributed a second survey on May 29, 2016 via an emailed invitation to 34 participants of the previous workshops. These participants were determined to be experts on the region through identified area of expertise or job title, which was both information collected through participant sign in sheets at both workshops. I sent invitation reminder emails on June 13, 2016 and July 6, 2016. The survey link closed on July 11, 2016. Nine participants completed the entire electronic survey. One respondent did not complete the entire survey. A full copy of invitation emails and the full survey is available in Appendix C.

I built the survey using the online platform, Qualtrics[1] (Qualtrics, Provo, UT). The survey began with a consent form (CHS #23155) and respondents were obligated to date and sign for the survey to continue. The survey was divided into four sections: reef fishes, corals and hard-

[1]Qualtrics software, Version 6-7, 2016 of Qualtrics. Copyright © 2016 Qualtrics. Qualtrics and all other Qualtrics product or service names are registered trademarks or trademarks of Qualtrics, Provo, UT, USA. http://www.qualtrics.com.

bottom, pelagic fishes, and the water body. Each section had the same question structure, with specificity given for each ecosystem component. The question structure asked respondents to identify drivers present in West Hawai‘i, connect identified drivers to pressures, distinguish which components of the ecosystem interact, and if they influence ecosystem services. Survey answers were pre-populated with data from previous workshops, and respondents selected answers by clicking on appropriate option(s). Answer forms had three blank spaces to ensure that respondents could include unique relationships that may have been left out.

Targeted Management Interview (September 2016)

I conducted an in-depth interview to assess the competency of research methods to categorize components of the ecosystem, integrate place-based knowledge, and identify monitoring indicators. The interview took place on September 21, 2016, with Dr. Jamison Gove, a scientist who has been studying Hawai‘i's ecosystems for ten years, and specifically West Hawai‘i for the last two years. Dr. Jamison Gove is the lead scientist for the West Hawai‘i IEA, and an integral part of this research. The interview consisted of five questions, and lasted for approximately 45 minutes. A full transcription of the interview is in Appendix D. The questions asked were intended to assess the whether this research captured existing social and ecological processes in West Hawai‘i, if the process seemed to successfully facilitate community and stakeholder communication, and if results of this research could be used to prioritize management.

Results

Symposium of West Hawai‘i's Marine Environment (September 2014)

Conceptual Ecosystem Models

The North and South groups identified drivers and pressures affecting the state of the coral reef ecosystem (*Figure 4*). The presence of a driver or pressure in only one of the regional CEMs may mean it is absent from the other region, or it could mean that groups did not identify the pressure or driver in their discussions for the other region. The fewer number of drivers and pressures in the North CEM may be because fewer groups focused on the North (two North groups, three South groups), or it may reflect the region.

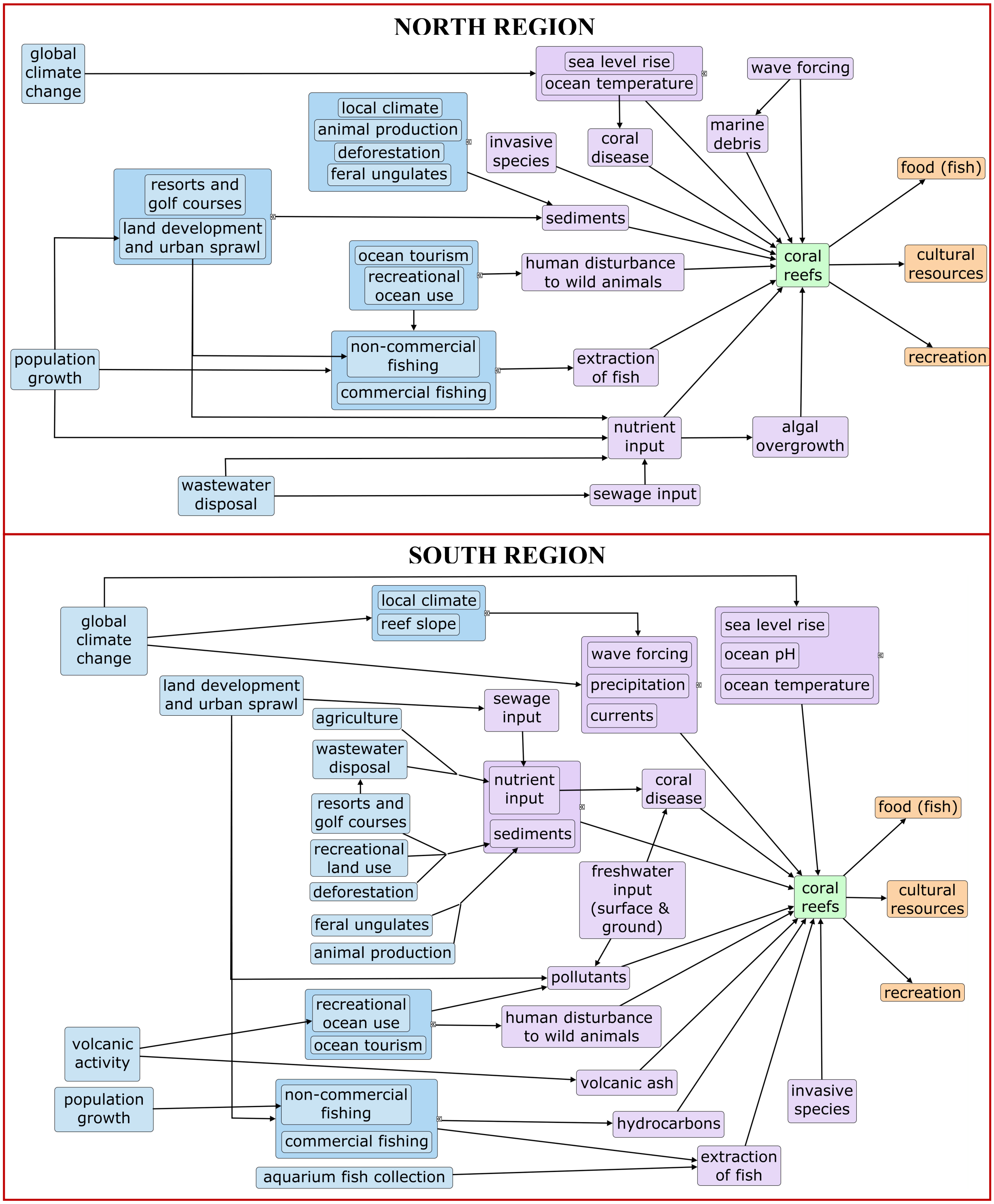

Figure 4: North and South West Hawai‘i Conceptual Ecosystem Models. Participants of the activity held at the Symposium of West Hawai‘i’s Marine Environment (2014) identified drivers (blue) and pressures (purple) that influence the coral reefs, and ecosystem services (orange) impacted by coral reefs.

The distal drivers for the North and South region were global climate change and population growth, with the South region also including volcanic activity. Proximal drivers were primarily anthropogenic (e.g., land development, deforestation, and animal production). The only naturally occurring drivers were local climate, reef slope, and volcanic activity. All North CEM drivers were also present in the South CEM. The drivers that existed only in the South model were reef slope, volcanic activity, agriculture, recreational land use, and aquarium fish collection.

Pressures, the direct cause of change to the state of the coral reef ecosystem, included biophysical pressures (e.g., wave forcing and freshwater input), but pressures derived from human-use dominated both CEMs (e.g., pollution, extraction of fish). The pressures identified as influencing the state of the coral reef ecosystem in each region were similar, with notable regional differences. All pressures identified in the North CEM were also present in the South CEM, except for marine debris and algal overgrowth. The South CEM identified more physical pressures than the North CEM (i.e., volcanic ash, currents, ocean temperature, precipitation, and freshwater input). The pollutants pressure (generated from the drivers, recreational ocean use and ocean tourism) consisted of sunscreen and other chemicals that may enter the water through human use of the ocean.

Both CEMs included ocean tourism (e.g., dolphin and Manta ray boat tours) and recreational ocean use (e.g., snorkeling, SCUBA diving, and kayaking) as drivers of human interaction with animals (a pressure). In both CEMs, commercial fishing and non-commercial fishing drive extraction of fish; however, the South CEM also included aquarium fish collection as a driver. In the South CEM, freshwater input (surface and groundwater) transported pollutants to the coral reef. Nutrient input and sediments directly affected the coral reef and coral disease.

Although widely similar, the drivers in both CEMs did contain some differences. In the North, population growth and land development were identified as causing nutrient input. In the South, agriculture and animal production were identified as creating nutrient input to coral reefs. The South model included recreational land use as a unique driver for sediments. The North model included local climate, and land development and urban sprawl as unique drivers for sediment export to coral reefs. Fishing was split into commercial and non-commercial. In the North region, population growth (distal driver) and land development and urban sprawl (proximal drivers) both affected commercial and non-commercial fishing. In the South region, land development and urban sprawl also affected both commercial and non-commercial fishing; however, population growth specifically affected non-commercial fishing.

Indicators

The group activity asked participants to create a list of potential ecosystem monitoring indicators for North and South West Hawai‘i that could be used to montior key ecosystem attributes (i.e., drivers, pressures, components of state, ecosystem services, and/or interactions between these). The complete list of suggested indicators is available in the Symposium Workshop Report. The results from the group activity provided justification in selecting indicators for the West Hawai‘i Integrated Ecosystem Assessment: Ecosystem Trends and Status Report (PIFSC, 2016) (*Table 1*). All social dimension indicators in this report were identified using the North and South CEMs (on-site disposal systems and nearshore fisheries extraction were also identified through relevant literature).

Table 1: List of ecosystem monitoring indicators identified by the North and South Conceptual Ecosystem Model selected by the West Hawai‘i Integrated Ecosystem Assessment.

Identified Indicators	
Population Growth	Juvenile Yellow Tang
Number of Visitors	Macro-algae Cover
Shoreline Modification	Coral Disease
New Development	Pacific Decadal Oscillation
On-Site Disposal Systems: Total Effluent & Nitrogen Flux	Commercial and Non-Commercial Fishing Pressure
On-Site Disposal Systems: Total Number	Rainfall
Multivariate ENSO Index	Coastal Sea Level
Invasive Algae	Sea Surface Temperature
Invasive Fish	Thermal Stress Anomaly
Mean Fish Length	Wave Power
Herbivore Biomass	

Hawai‘i Conservation Conference (August 2015)

The Water Body

The Water Body CEM identified 65 total interactions. There were 20 driver-to-pressures interactions, 21 pressure-to-ecosystem state interactions, and 24 ecosystem state-to-ecosystem service interactions (
Figure **5**). Participants determined the key pressures directly affecting the water body were nutrient input and freshwater input.

The highest weighted pressures that had a direct effect on the water body were ocean temperature (4), extreme events (e.g. hurricane, tsunami; 5), nutrient input (5), pathogens (5), pharmaceuticals (5), hydrocarbons (e.g., motor oil; 5), pesticides (5), and freshwater input (5). The pressures weighted as having some direct effect on the water column were sea level rise (2), ocean pH (3), sediments (3), other contaminants (e.g. bromine pools, sunscreen; 3), habitat destruction (3), marine debris (3), human interaction with animals (1; this pressure weighting was marked as uncertain), and extraction of fish (3). The pressures weighted as having no direct effect on the water body were coral disease, algal overgrowth, flooding, wind, and wave forcing.

The second question of the activity asked about proportional impacts (i.e., what proportion of any ecosystem component or ecosystem service is directly affected by an associated pressure or ecosystem component, respectively). The pressures ranked as having the greatest proportional impact on the water body were ocean temperature, nutrient input, pathogens, and pharmaceuticals (each scored 10% for the second question of the activity). The pressures with moderate proportional impact were sea level rise (5%), ocean pH (7%), hydrocarbons (5%), pesticides (5%), extraction of fish (5%), and freshwater input (7%). The pressures with the lowest proportional impact were extreme events (3%), invasive species (1%), precipitation (1%), and lava (1%). Participants determined that the water body had the strongest direct effect (score of 5 out of 5) on all ecosystem services listed.

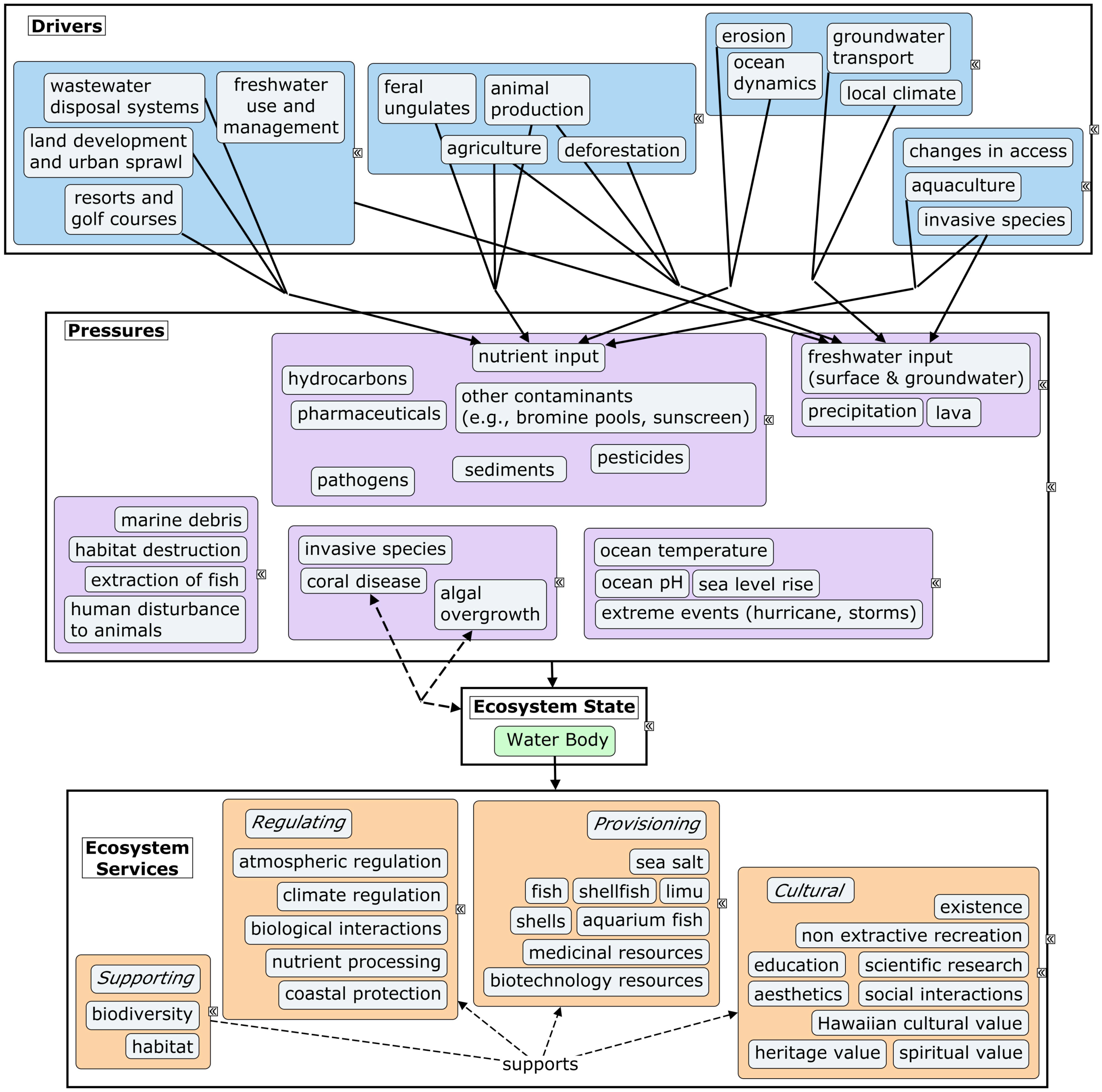

Figure 5: The Water Body Conceptual Ecosystem Model created at Hawaiʻi Conservation Conference workshop. Each box represents a driver, pressure, ecosystem state, or ecosystem service. Arrows from the Drivers box represent interactions between each smaller box and associated pressures. Arrow from Pressures box represents interactions between each smaller box within Pressures and The Water Body. Arrow from the Ecosystem State box to Ecosystem Services box represents interactions between The Water Body and each Ecosystem Services smaller box.

Reef Fishes

The Reef Fishes CEM identified 74 total interactions. There were 40 driver-to-pressure interactions, 15 pressure-to-ecosystem state interactions, and 19 ecosystem state-to-ecosystem services interactions (*Figure 6*).

The highest weighted pressures that had a direct effect on reef fishes were nutrient input (4), sediments (4), habitat destruction (5), and extraction of fish (5). The pressures weighted as having some direct effect on reef fishes were ocean temperature (3), ocean pH (2), extreme events (3), pathogens (1), marine debris (1), human interaction with animals (1), invasive species (1), coral disease (1), algal overgrowth (2), flooding (3), and freshwater input (surface and groundwater; 2). The pressures weighted as having no direct effect on reef fishes were sea level rise, other contaminants, pharmaceuticals, hydrocarbons, pesticides, wind, wave forcing, precipitation, and lava. The reef fishes group determined that the key pressures directly affecting reef fishes were nutrient input, sediments, and habitat destruction.

The second question of the activity asked about proportional impacts. The pressures ranked as having the greatest proportional impact on reef fishes were habitat destruction and extraction of fish (25% each). The pressures that scored moderate proportional impact (10% each) were nutrient input and sediments. Ocean temperature, extreme events, and flooding scored low proportional impact (5% each). The pressures with the lowest proportional impact were ocean pH (2%), pathogens (1%), marine debris (1%), human interaction with animals (1%), invasive species (1%), coral disease (1%), and algal overgrowth (2%).

The ecosystem services that the reef fishes had the strongest direct effect on (score of 5 out of 5) were aquarium fish, aesthetic environment, non-extractive recreation, scientific research, education, cultural practices, heritage value, spiritual value, biological interactions, nutrient processing, biodiversity, and habitat. Ecosystem services that reef fishes had a weaker direct effect on were fish (as food; 3), shellfish (1), limu (3), medicinal resources (3), biotechnology (1), social interaction (3), and coastal protection (4). The ecosystem services that score zero were existence, shells, climate regulation, and atmospheric regulation.

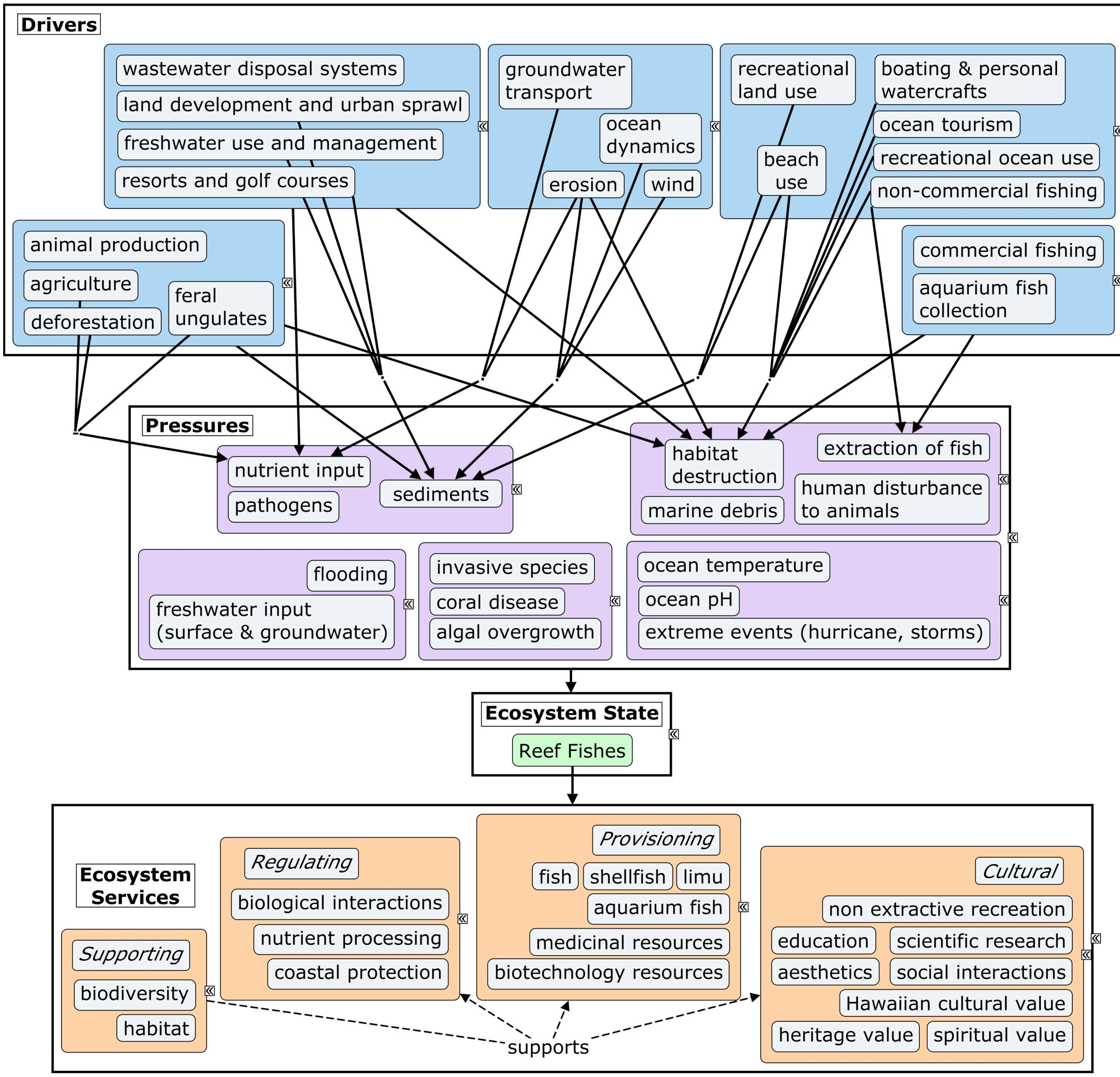

Figure 6: The Reef Fishes Conceptual Ecosystem Model created at Hawaiʻi Conservation Conference workshop. Each box represents a driver, pressure, ecosystem state, or ecosystem service. Arrows from the Drivers box represent interactions between each smaller box and associated pressures. Arrow from Pressures box represents interactions between each smaller box within Pressures and Reef Fishes. Arrow from the Ecosystem State box to Ecosystem Services box represents interactions between Reef Fishes and each Ecosystem Services smaller box.

Pelagic Fishes

The Pelagic Fishes CEM identified 47 total interactions. There were nine driver-to-pressure interactions, 19 pressure-to-ecosystem state interactions, and 19 ecosystem state-to-ecosystem service interactions (*Figure 7*). The key pressures identified as having the strongest affect on pelagic fishes were ocean temperature, habitat destruction, and extraction of fish.

The highest weighted pressures that have a direct effect on pelagic fishes were ocean temperature (5; due to early spawning) ocean pH (4; group was uncertain, but noted there is more a threat in the future and a need for more research), habitat destruction (4), and extraction of fish (5). The pressures weighted as having some direct effect on the pelagic fishes were extreme events (2), nutrient input (3), pathogens (1; with uncertainty), sediments (2), other contaminants (1-2), pharmaceuticals (1-2; high level of uncertainty), hydrocarbons (1), pesticides (3), marine debris (3), human interaction with animals (3), invasive species (1), coral disease (1), algal overgrowth (1), freshwater input (2; surface and groundwater), and wind (2). Sea level rise, flooding, wave forcing, precipitation, and lava were identified to have no direct affect on pelagic fishes.

The second question of the activity asked about proportional impacts. The pressures ranked as having the greatest proportional impact on pelagic fishes were ocean temperature (20%), habitat destruction (25%), and extraction of fish (35%). The pressures with moderate proportional impact were ocean pH (5%), nutrient input (3%), pesticides (3%), marine debris (3%), human interaction with animals (3%), and freshwater input (3%). The pressures with little proportional impact were extreme events (<1%), pathogens (<1%), sediments (<1%), other contaminants (<1%), pharmaceuticals (<1%; highly uncertain), hydrocarbons (<1%; e.g., motor oil), invasive species (<1%), coral disease (<1%), and algal overgrowth (<1%).

The ecosystem services that the pelagic fishes ecosystem component had the strongest direct effect on (score of 5) were fish (for food), non-extractive recreation, cultural practices, heritage value, spiritual value, social interaction, biological interactions, and biodiversity. Ecosystem services that pelagic fishes had a weaker effect on were medicinal resources (3), biotechnology resources (1), non-food use of fish (2), aesthetic environment (3), existence (4), scientific research (4), education (4), nutrient processing (1), and habitat (2). Pelagic fishes do not contribute to shellfish, limu, aquarium fish, shells, climate regulation, atmospheric regulation, and coastal protection.

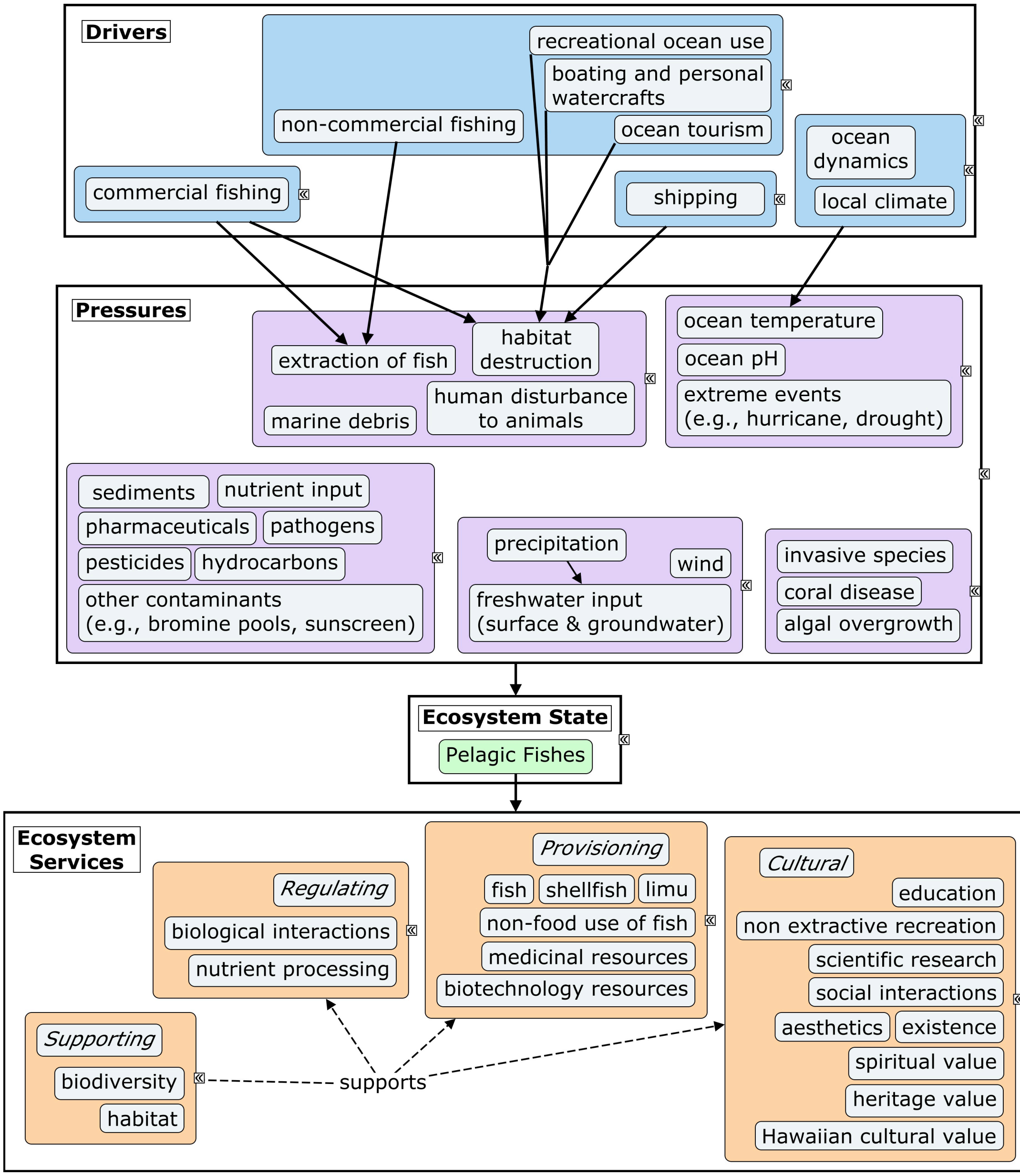

Figure 7: The Pelagic Fishes Conceptual Ecosystem Model created at Hawaiʻi Conservation Conference workshop. Each box represents a driver, pressure, ecosystem state, or ecosystem service. Arrows from the Drivers box represent interactions between each smaller box and associated pressures. Arrow from Pressures box represents interactions between each smaller box within Pressures and Pelagic Fishes. Arrow from the Ecosystem State box to Ecosystem Services box represents interactions between Pelagic Fishes and each Ecosystem Services smaller box.

Corals and Hard-Bottom

The Corals and Hard-Bottom CEM identified 48 total interactions. There were 25 pressure to state interactions and 23 state to ecosystem service interactions (*Figure 8*). The highest weighted pressures that had a direct effect on the corals and hard-bottom were ocean temperature (5), extreme events (4), nutrient input (5), pesticides (5), habitat destruction (5), human interaction with animals (5; i.e., corals), extraction of fish (5), coral disease (5), algal overgrowth (5), wave forcing (5), injection wells (5), cesspools and septic tanks (5), and boat damage to reefs (5). The pressures weighted as having some direct effect on the corals and hard-bottom were sea level rise (1), ocean pH (2), sediments (3), other contaminants (1; e.g., sunscreen), hydrocarbons (3; e.g., hydrocarbons), invasive species (3), flooding (3), freshwater input (1; surface and groundwater), wind (2), and currents (3). The corals and hard-bottom group did not have time to complete the portion of the activity linking driver influence to pressures.

Participants identified all services to be strongly affected by the state of the coral and hard-bottom (scored 5), except limu (3), medicinal resources (4), biotechnology resources (4), climate regulation (2), and atmospheric regulation (1).

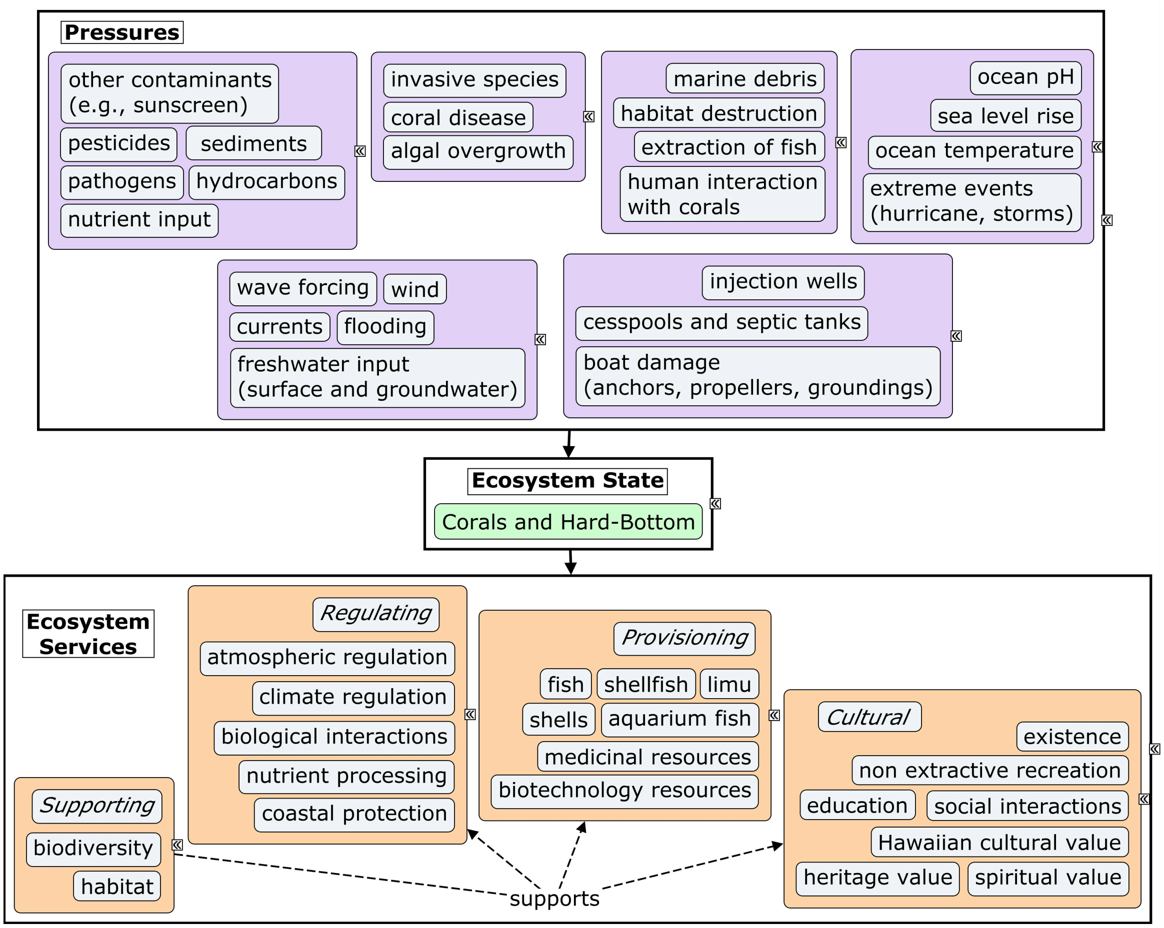

Figure 8: Corals and Hard-Bottom Conceptual Ecosystem Model created at Hawai'i Conservation Conference workshop. Each box represents a pressure, ecosystem state, or ecosystem service. Arrow from Pressures box represents interactions between each smaller box within Pressures and Corals and Hard-Bottom. Arrow from the Ecosystem State box to Ecosystem Services box represents interactions between Corals and Hard-Bottom and each Ecosystem Services smaller box.

Pressure-to-ecosystem State Interaction Scores

Groups identified 73 pressure-to-ecosystem state interactions (i.e., 73 pressures affected coral reefs, reef fish, pelagic fish, and the water body; **Table 2**). The corals and hard-bottom group identified 20 interactions, the reef fishes group identified 15 interactions, the pelagic fishes group identified 19 interactions, and the water body group identified 19 interactions. Cumulative interaction strengths identified the strongest pressures, which were extraction of fish (18), ocean temperature (17), nutrient input (17), and habitat destruction (17). Cumulative interaction strengths also identified the most impacted ecosystem components, which were corals and hard-bottom and the water body.

In addition to each score, groups recorded general discussion notes and comments pertaining to specific scores. The corals and hard-bottom group specifically noted that the pressure, nutrient input, was originating primarily from golf courses. Herbicides were explicitly included under the category of pesticides. The group also added additional pressures that were determined to be missing: currents, injection wells, cesspools and septic tanks, and boat damage (i.e. damage from anchors, propellers, and groundings).

Some groups noted that their answers had high uncertainty. The pelagic fishes group noted uncertainty in the score for ocean pH, pathogens, and pharmaceuticals. The group added droughts to the list defining the pressure, extreme events (e.g., hurricanes or tsunamis). Participants expanded the definition of habitat destruction to include Fish Aggregating Devices, noise, and physical and water column disruption. Lastly, the group noted that the pressure, human disturbance to animals, should refer specifically to disturbance caused to sharks and manta rays. The water body group scored other contaminants and human disturbance to animals with uncertainty. The group also noted that two pressures, coral disease and algal overgrowth, were not affected by the water body. Conversely, the quality of the water body affected these two pressures.

Table 2: Ecosystem pressure-to-ecosystem state matrix. Workshop participants decided each matrix value. Cumulative effects and cumulative impacts represent the row and column sums, respectively. Cells that do not represent a relationship are defined as "not a number" (nan). Red cells represent identified but not scored relationships.

From Ecosystem Pressure	**To Ecosystem State**				
	Corals & Hard-Bottom	Reef Fishes	Pelagic Fishes	The Water Body	**Cumulative Effect of Pressure**
Extraction of Fish	5	5	5	3	18
Ocean Temperature	5	3	5	4	17
Nutrient Input	5	4	3	5	17
Habitat Destruction	5	5	4	3	17
Extreme Events	4	3	2	5	14
Pesticides	5	nan	3	5	13
Sediments	3	4	2	3	12
Ocean pH	2	2	4	3	11
Marine Debris	4	1	3	3	11
Human disturbance to animals	5	1	3	1	10
Freshwater Input	1	2	2	5	10
Hydrocarbons	3	nan	1	5	9
Non-native Invasive Species	3	1	1	3	8
Algal Overgrowth	5	2	1	nan	8
Pathogens	nan	1	1	5	7
Coral Disease	5	1	1	nan	7
Pharmaceuticals	nan	nan	1	5	6
Flooding	3	3	nan	nan	6
Other Contaminants	1	nan	1	3	5
Wave Forcing	5	nan	nan	nan	5
Wind	2	nan	2	nan	4
Sea Level Rise	1	nan	nan	2	3
Precipitation	nan	nan	nan	2	2
Lava	nan	nan	nan	1	1
Cumulative Impact to State	72	38	45	66	

Ecosystem State to Ecosystem Service Interaction Scores

Groups identified a total of 81 ecosystem state to ecosystem service interactions (*Table 3*). The corals and hard-bottom group identified 23 interactions, the reef fishes group identified 19 interactions, the pelagic fishes group identified 16 interactions, and the water body group identified 23 interactions. Groups then determined relative interaction strengths for each ecosystem component to ecosystem service (**Figure 11**). Cumulative interaction strengths identified the most impacted ecosystem services, which were biodiversity (20), biological interactions (20), non-extractive recreation (20), Hawaiian cultural value (20), heritage value (20), and spiritual value (20). Cumulative interaction strengths also identified the cumulative effect of individual ecosystem components to all ecosystem services. The water body had the strongest effect (115 out of 115). Corals and hard-bottom had the second strongest effect (104 out of 115).

Table 3: Ecosystem state to ecosystem service matrix. Workshop participants decided each matrix value. Cumulative effects and cumulative impacts represent row and column sums, respectively. Cells that represent no relationship are labeled "not a number" (nan). Red cells represent identified but not scored relationships.

To Ecosystem Service	**From Ecosystem State**				
	Corals & Hard-Bottom	Reef Fishes	Pelagic Fishes	The Water Body	**Cumulative Impact to Ecosystem Service**
Biodiversity	5	5	5	5	20
Biological Interactions	5	5	5	5	20
Non-extractive Recreation	5	5	5	5	20
Hawaiian Cultural Value	5	5	5	5	20
Heritage Value	5	5	5	5	20
Spiritual Value	5	5	5	5	20
Scientific Research	5	5	4	5	19
Education	5	5	4	5	19
Fish	5	3	5	5	18
Aesthetic Environment	5	5	3	5	18
Social Interaction	5	3	5	5	18
Habitat	5	5	2	5	17
Nutrient Cycling	5	5	1	5	16
Aquarium Fish	5	5	nan	5	15
Medicinal Resources	4	3	3	5	15
Coastal Protection	5	4	nan	5	14
Existence	5	nan	4	5	14
Shellfish	5	1	nan	5	11
Limu	3	3	nan	5	11
Biotechnology Resources	4	1	1	5	11
Shells	5	nan	nan	5	10
Climate Regulation	2	nan	nan	5	7
Atmospheric Regulation	1	nan	nan	5	6
Cumulative Effect of State	104	78	62	115	

Workshop Participant Survey (August 2015)

Twenty-one workshop participants took the optional survey (87% of all participants). Eight identified as a state or federal agency staff, three identified as a resource manager, seven identified as community members of West Hawaiʻi, and three identified as "other" (non-profit, graduate student, and scientist). One participant gave two answers for this question, and one participant did not answer this question. The survey was answered on a scale of 1 (strongly disagree) to 10 (strongly agree) (*Table 4*). One participant did not answer Question 3.

Based on the survey, most participants increased their knowledge or gained a new skill from the workshop, and plan to use something learned from the workshop in their professional lives (**Table 4**). Approximately half of participants agreed they may use something learned from the workshop in their daily life, and two-thirds of participants agreed they changed how they think about land-sea management based on their participation. Every participant agreed that the development of CEMs is useful for resource management in West Hawaiʻi.

Some participants recorded examples or comments for individual questions, which are available in full in Appendix B. Participants expressed that they learned about using indicators for scientific research, and appreciated that the workshop engaged community members in the management process.

Table 4: Responses from the Hawaiʻi Conservation Conference workshop optional survey (n=21). Participants responded to questions on a scale of 1 (strongly disagree) to 10 (strongly agree).

Question	Mean (± sd)	Mode
1) I increased my knowledge or gained a new skill from today's workshop.	7.05 (±6.32)	8
2) I plan on using information that I learned today in my work.	7.29 (±6.53)	8
3) I plan on using information that I learned today in my daily life.	5.35 (±4.85)	8
4) I changed how I think about land-sea management based on today's workshop.	5.67 (±4.87)	6
5) I think the DPSIR model and process is useful for resource management in Hawaii.	8.24 (±7.66)	10

Electronic Survey (June 2016)

The electronic survey identified missing interactions between drivers and pressures, ecosystem components, and ecosystem components to ecosystem services. Results from this survey were combined with results from HCC to create a list of total identified components (drivers, pressures, ecosystem components, and ecosystem services) and interactions within each of the four Ecosystem State CEMs (**Table 5**).

The survey asked for any additional comments pertaining to that section of the survey. One comment expressed a need for a network of no-take reserves that encompass 30% of the state waters, in order to increase resiliency and replenish overfished areas. Another comment expressed that the aquarium fishery has not only survived but flourished as a direct result of good management practices, and that the coral die-off provided yellow tangs (*Zebrasoma flavescens*) with an abundance of turf algae to feed on. This commenter also noted that the "influx of Micronesians and Marshal *[sic]* Island people have *[sic]* led to a major reduction of non-aquarium fish" and that night spear fishing is a direct cause for decreased parrotfish (*Scaridae*) biomass, and therefore should be banned. Another comment mentioned that herbivorous fishes are a keystone species in the marine environment, and are critical for community stability, resilience, and ecosystem function. One individual noted that all vehicles and boats add to the hydrocarbon concentrations in the atmosphere and ocean. Another advised that management should create regulations that focus on lowering the amount of fish extracted.

Table 5: Total identified components and interactions within each Ecosystem State CEM from the HCC workshop and electronic survey.

	Total Components	**Total Interactions**
Corals	78	315
Reef Fishes	78	337
Pelagic Fishes	61	109
Water Body	73	187

Discussion

This research used participatory methods to comprehensively characterize social and ecological drivers, pressures, ecosystem components, and ecosystem services of West Hawai‘i's marine ecosystem and assess the strengths of interactions among them. Indicators used to monitor focal ecosystem attributes were defined by workshop participants, and evaluated to determine if the identified strongest ecosystem interactions are currently being monitored in West Hawai‘i. This research engaged community members in management, facilitated collaboration among diverse groups, and collected place-based knowledge. An overview of this research and how it links within the management process is displayed in *Figure 9*. This research facilitated a participatory process that gathered place-based knowledge to build conceptual ecosystem models and identify ecosystem monitoring indicators. Using this information, management is better informed to create responses and prioritize action-based policy. To best inform management in West Hawai‘i, limitations of the approach used in this research are addressed below, along with recommendations for the future.

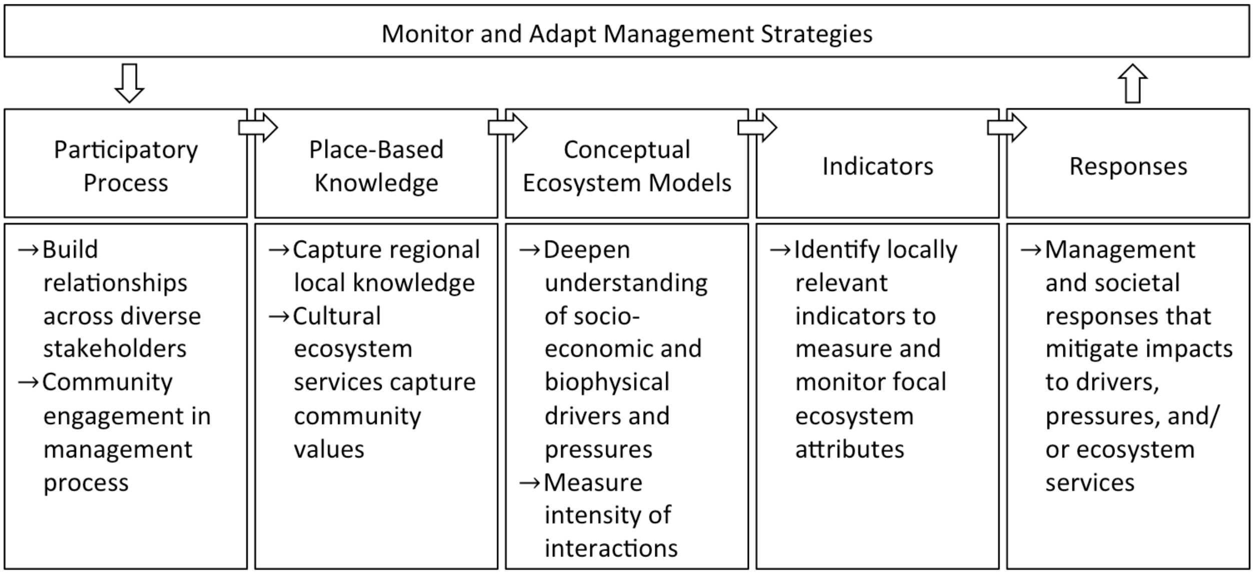

Figure 9: A diagram overview of this research, and how it will fit into the management process within West Hawai‘i. Adapted from Fletcher et al. (2010) and Levin et al. (2015).

Characterizing the Social-Ecological System

Extraction of fish strongest cumulative pressure

Extraction of fish (i.e., non-commercial and commercial fishing, including aquarium fish collection) was a locally perceived key pressure influencing reef and pelagic fishes, and cumulatively had the strongest effect on ecosystem components (**Figure 10**). Current estimates of target fish biomass in North-West Hawai‘i reefs are approximately 20% lower than historical averages, confirming that overfishing is a current pressure in West Hawai‘i (Minton et al., 2015). Ocean temperature was also identified as a key pressure affecting reef and pelagic fishes, and cumulatively had the second strongest effect on ecosystem components, along with nutrient input and habitat destruction (**Figure 10**). In West Hawai‘i, recorded sea surface temperature is rising, leading to massive coral bleaching events (Rosinski and Walsh, 2016); and nutrients are entering the marine environment in multiple areas along the coast, with levels predicted to increase due to coastal development (Couch CS et al., 2014; Weijerman et al., 2014).

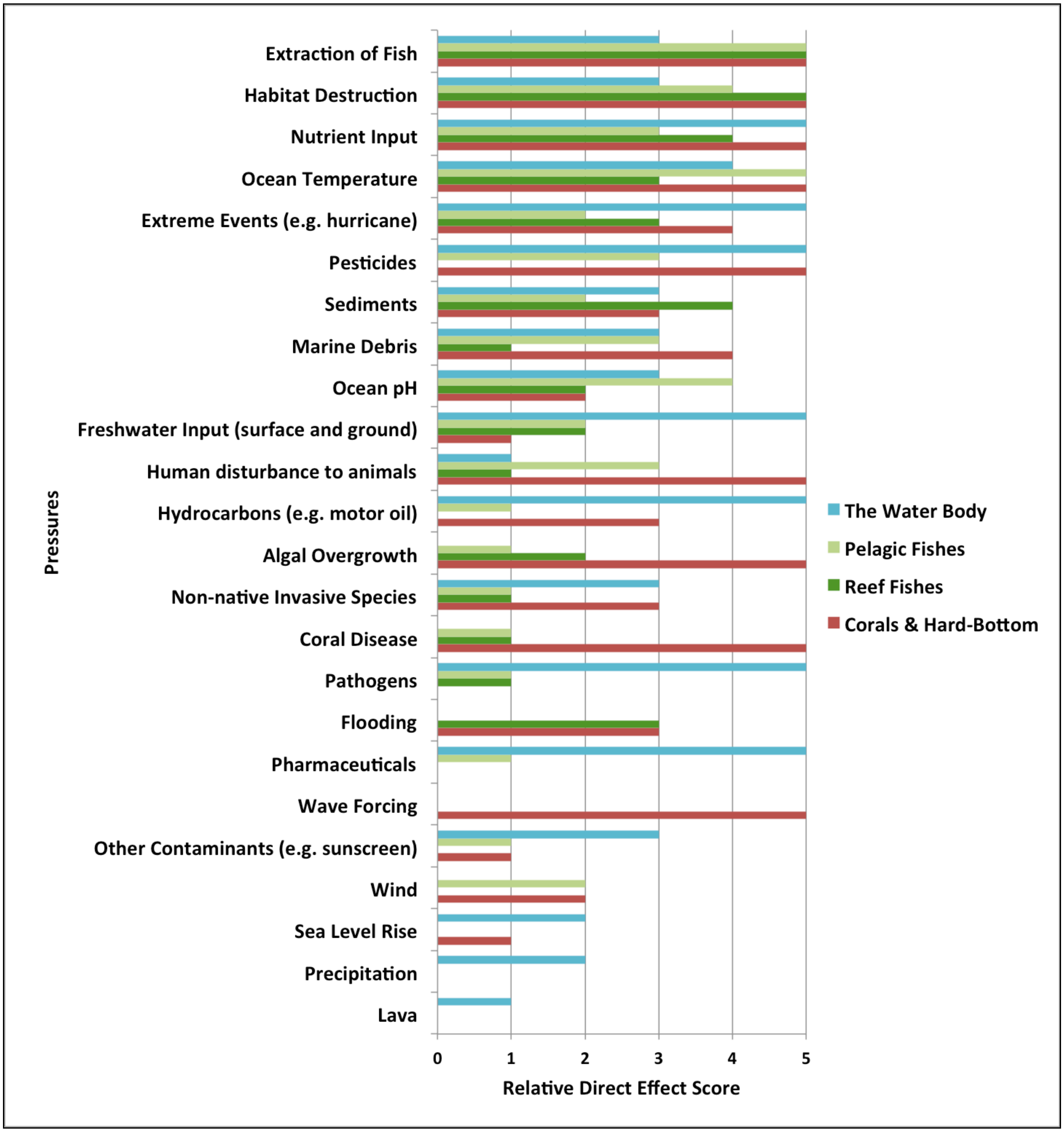

Figure 10: Participant-identified relative strengths of the direct effect of pressures onto an ecosystem component (corals, reef fishes, pelagic fishes, and the water body). Strength is recorded on the scale of 0 (no effect) to 5 (strongest effect). Pressures are in order of strongest cumulative effects (top) to weakest (bottom).

Water body, corals and hard-bottom most impacted ecosystem components

Cumulatively, participants identified the water body and corals and hard-bottom as the most impacted of all ecosystem components (**Table 2**). Coral reefs in other locations have also been identified as the most impacted ecosystem component in a similar study (Cook et al., 2013). The water body and corals and hard-bottom were also the two ecosystem components that had strongest cumulative effect on ecosystem services (**Table 3**). Since these components underpin much of the ecosystem, it may be important to direct management actions towards strategies that conserve or increase resiliency of both, to benefit the provisioning of all ecosystem services.

Biodiversity, biological interactions, cultural services most impacted ecosystem services

The most impacted ecosystem services identified by participants were biodiversity, biological interactions, and four cultural services (**Figure 11**). Therefore, these services may be the most susceptible to declines in ecosystem state (Cook et al., 2013). Biodiversity is a critical supporting ecosystem service, and was identified as the most impacted service in a study conducted via similar methods in the Gulf of Maine (Altman et al., 2011). Also, biodiversity supports biological interactions (i.e., the species interactions that support, continue, and provide valuable ecosystem functions). Cultural services are important to society and resource management in the state of Hawai‘i, yet few policies are in place that act to conserve or protect them (Pleasant et al., 2014). This result points to a need for management strategies to prioritize conservation of these ecosystem services. Additionally, participants identified that all ecosystem components contribute to almost all ecosystem services (only eight services were not directly affected by all components) emphasizing the need for a holistic management approach, such as EBM.

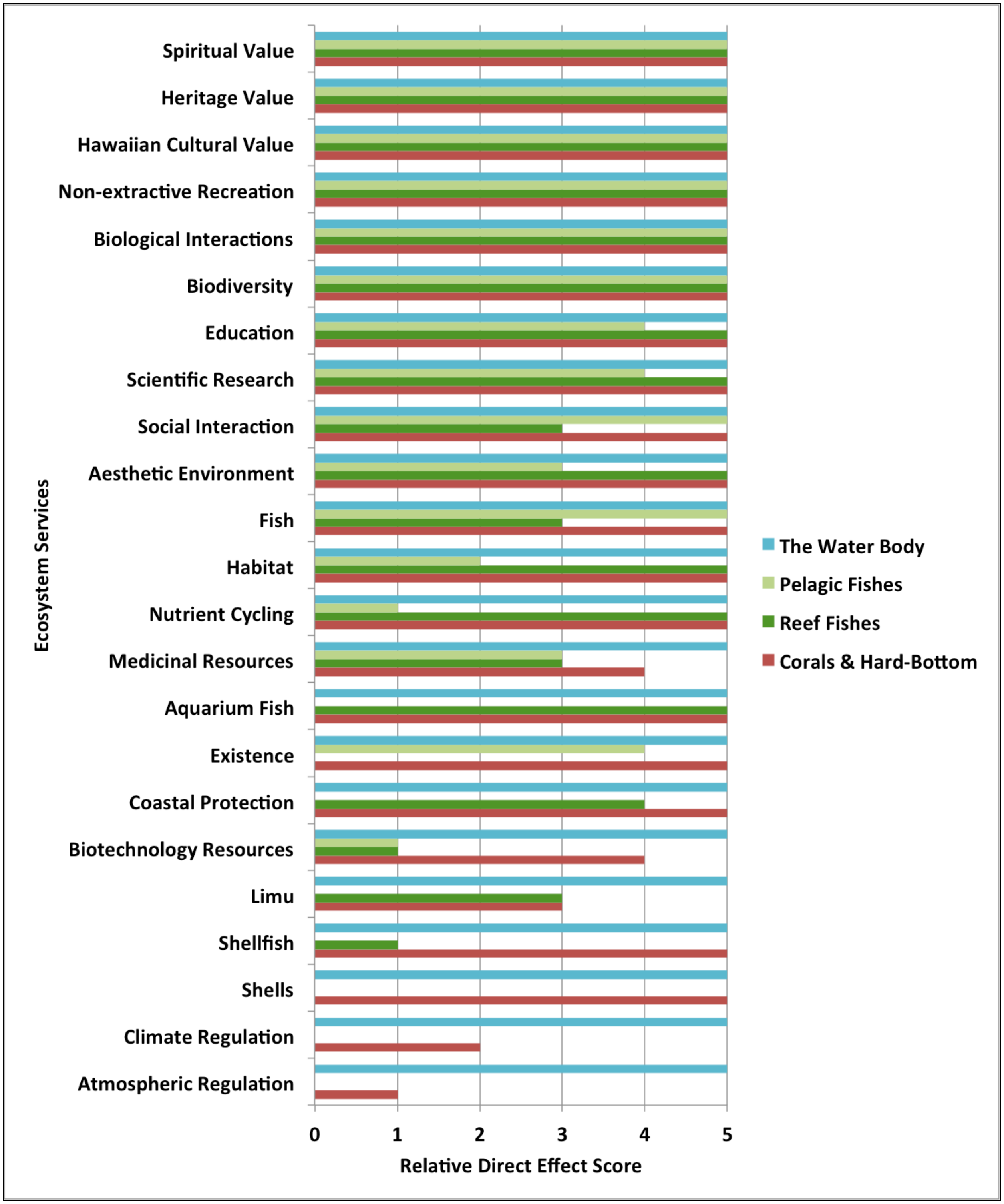

Figure 11: Participant-identified relative strengths of the direct effect of an ecosystem component (corals, reef fishes, pelagic fishes, and the water body) onto an ecosystem service. Strength is recorded on the scale of 0 (no effect) to 5 (strongest effect). Ecosystem services are in order of strongest cumulative effects (top) to weakest (bottom).

Management significance of social-ecological system characterization

Based on our results, resource managers in West Hawaiʻi can prioritize action to address the strongest pressures that are likely to contribute most to ecosystem state resilience in the region (Cook et al., 2013). For example, extraction of fish can be addressed through local management strategies, such as designating marine reserves or creating legally enforceable fishing regulations. Local management can also address key pressures that are created through global mechanisms, and may be perceived as harder to address at a local level. For example, rising ocean temperatures can be mitigated by actions that increase ecosystem resiliency, such as reducing sediment and nutrient input to the system. Managers can similarly direct action to the most impacted ecosystem components or ecosystem services.

Indicators

In both workshops, participants identified locally relevant indicators to monitor focal ecosystem attributes (**Table 1**). These indicators, along with others selected through relevant literature, were published in the West Hawaiʻi Integrated Ecosystem Assessment: Ecosystem Trends and Status Report (IEA Report), to be used in monitoring the West Hawaiʻi near-shore and marine environment (PIFSC, 2016). By comparing the strongest pressures and ecosystem services identified in this research with indicators in the IEA Report, we can evaluate if focal attributes of the region are being adequately monitored.

Key ecosystem attributes are not currently monitored

My evaluation revealed that many key ecosystem attributes (i.e., drivers, pressures, components of state, ecosystem services, and/or interactions between these) are not currently monitored, or may be inadequately monitored, while others have redundant indicators. For example, there are a total of six indicators that monitor reef fish communities, and one indicator to specifically monitor fishing activity. This may be appropriate for monitoring reef fishing pressure. Similarly, ocean temperatures are already monitored both directly though the sea surface temperature indicator and indirectly through the Pacific decadal oscillation, multivariate ENSO index, and rainfall indicators (PIFSC, 2016). Conversely, nutrient input also had perceived strong effects on the ecosystem but only two indicators monitor nutrient input; the total number of on-site waste disposal systems and total effluent released annually. These indicators do not necessarily capture how much nitrogen reaches the marine environment (PIFSC, 2016), and may exclude other important nutrient sources as identified by workshop participants (e.g., run-off from golf course fertilizers). Terrestrial habitat destruction, another identified strong pressure, is only monitored broadly through recent records (2005-2010) of shoreline modification and land development. Understanding the strongest pressures to the ecosystem can help to ensure that key influential ecosystem attributes are effectively monitored, or evaluate if more indicators are required.

Many indicators that monitor specific ecosystem attributes could also provide indirect information about two of the most affected ecosystem services, biodiversity and biological interactions, because these services are reflected by the condition of other ecosystem components (e.g., indicators such as total fish abundance, fish species richness, coral cover, and coral disease are designated to monitor reef fishes and coral communities, but will also reflect biodiversity and biological interactions). The most impacted cultural services (non-extractive recreation, Hawaiian cultural value, heritage value, and spiritual value) are not well covered, perhaps because it is harder to monitor cultural services through biophysical or monetary indicators traditionally used to monitor some cultural services, such as recreation (Atkinson et al., 2012). Further research may be required to determine applicable indicators or proxies for assessing cultural services.

Participatory Process

An important part of this process was creating opportunities for collaboration between resource managers, scientists, and community members. This allowed for establishing connections and building community trust in management (Levine and Feinholz, 2015). The methods used in this research provided valuable community empowerment and educational opportunities (**Table 4**), which are arguably the most important outcome of participatory methods (Fraser et al., 2006). This inclusion of society in management strategies is essential to the success of EBM (McLeod and Leslie, 2009).

Place-Based Knowledge

Many drivers and pressures identified in this research (**Figure 4**), such as climate change, fishing, and shoreline development, also emerged in similar CEM exercises done on other coral reef ecosystems adjacent to human societies (Kelble et al., 2013; Yee et al., 2014). However, unique drivers, pressures, and interactions were identified for the West Hawaiʻi region, including volcanic activity, aquarium fish collecting, and human interaction with animals. These differences highlight the need for place-based knowledge in system model development. For instance, while there were expected significant differences between North and South West Hawai‘i CEMs due to regional differences in precipitation, land use, and the physical environment, the CEMs created were very similar. Drivers identified in the North and South CEM had few differences, and were predominantly anthropogenic (e.g., population growth and land development/urban sprawl). Despite the existence of similar drivers, pressures identified contained multiple differences. For example, participants identified that population growth and land development caused nutrient input to the marine environment in the North. In the South, participants identified agriculture and animal production as causes of nutrient input to the marine environment. Differences in drivers can likely be attributed to differences in regional land use. Furthermore, managers and scientists alone could not have compiled the vast list of ecosystem services provided by this region and valued by the community. These place-specific results highlight the importance of conducting location-specific assessments; North-South differences reveal heterogeneous outcomes even over short distances.

Future Workshop Recommendations

After the HCC workshop, I asked workshop facilitators to provide feedback. From their feedback and my own experience, I created recommendations for replicating or furthering participatory workshops. Overall, the structure of the activity provided an environment that facilitated participation from the entire group. Participants shared a wide array of viewpoints and ideas largely without conflict. The organizational element provided by the DPSIR framework provided a common language among diverse participants, enabling workshop activity structure. While the DPSIR framework is not predominantly used to engage multiple sectors, include community members in management, or build quantitative models (Lewison et al., 2016), this research saw the opportunity to successfully employ the framework for these purposes.

My experience and feedback from facilitators offers several insights for future similar workshop design and management. Before beginning, workshop facilitators should go through a mock version of activities with the workshop team to ensure they understand objectives of both the individual workshop, and the goals of the entire process. They should also discuss new terminology and frameworks with participants to enhance understanding. Clarifying the spatial and temporal scale of the activity is also important before beginning.

Future workshops should begin by reviewing the entire process with participants, clearly describing how the individual workshop adds to the process, and give examples of similar processes. The significance of involving community members and capturing place-based knowledge can be highlighted during this introduction. Lastly, the duration of the activity should be no more than two hours, and involve fewer steps to hold participant interest. In the future, workshops could be held at times that are more accommodating to diverse schedules.

Addressing Challenges and Limitations

This process created a current working hypothesis of the West Hawaiʻi social-ecological system, but undeniably produced a simplified model due to the linear nature of the DPSIR-CEMs (Gari et al., 2015). These models do not include all feedbacks that exist in reality, nor do they capture interactions among components at the same level of the model (i.e., a pressure affecting a pressure; Gari et al., 2015). Moreover, while synergistic and antagonistic effects are inherent in complex systems such as the West Hawaiʻi region (Halpern et al., 2008), such feedbacks are not included in our CEMs. Finally, these CEMs have no precise spatial or temporal scale, which may be a requirement during management strategy development.

Inevitably, employing participatory methods to build CEMs will result in multiple limitations, including potentially biased data, uncertainties within results, and an oversimplification of the study system (Kelble et al., 2013; Lewison et al., 2016; Svarstad et al., 2008). Furthermore, data collection relies on participation of many stakeholders, which can be difficult to obtain. The data will undeniably be even more robust if individuals participate in multiple parts of the process (i.e., multiple workshops or surveys) and gain familiarity with the process. Participants can introduce bias in multiple ways, most notable by unintentionally providing incorrect information (Levine and Feinholz, 2015). They may also be more familiar and able to provide information for a particular region, which can unintentionally skew results. The spatial and temporal setting of workshops and surveys can also introduce bias. For example, the HCC workshop took place in the same summer as the largest coral-bleaching event recorded in West Hawaiʻi, which could have influenced identification of ocean temperature as a strong pressure. When the workshop takes place (day of week/time of day) influences who may be able to attend. The process also did not provide participants with a way to record uncertainty alongside information, and doing so could have increased willingness to provide information.

Conclusion

To support EBM in West Hawaiʻi, my research aimed to identify the locally perceived socio-economic and biophysical drivers that create pressures, understand how they interact and influence the near-shore and marine ecosystem, and ultimately impact the regional ecosystem services. Additionally, my research looked closely at the identified interacting components to assign weights to the interactions and identify indicators for ecosystem monitoring.

Understanding interactions within social-ecological systems can be a limiting factor for implementing EBM (Altman et al., 2011). The DPSIR-CEMs represent these interactions and their relative interaction strengths. Anthropogenic drivers and pressures dominated the system. Fishing, ocean temperatures, nutrient input, and habitat destruction were the strongest identified pressures. Knowing what pressures have the relatively strongest effect on a particular ecosystem component can help to inform resource managers and prioritize actions (Altman et al., 2011; Game et al., 2013).

Implementing EBM in Hawaiʻi requires collaboration between governing agencies, community involvement, and ecological and social data relevant to decision making (Tissot et al., 2009). My research included participatory methods that asked resource managers, scientists, and community members to define the interacting ecological, biophysical, cultural, and economic components of the region. Workshops provided opportunities for collaboration that created relationships that will exist beyond this research and benefit future management actions due to engagement and support of community members.

Moving forward, there is a need to define spatial or temporal scales of ecosystem attributes and interactions to account for feedbacks and synergistic interactions (Fletcher et al., 2014; Harvey et al., in press; Lewison et al., 2016). One way to accomplish this is through quantitative system models, which can also be used to predict the effects of management action and/or external drivers (e.g., climate change) within the system. These models also can predict social and ecological impacts to cultural ecosystem services (Harvey et al., in press), an important step in identifying a comprehensive set of indicators that span the social-ecological system in a timely and cost-effective manner.

Appendix A: Symposium Workshop Report

Symposium on Kailua Kona's Marine Ecosystem: Trends and Status
Led by: Pacific Island Fisheries Science Center Integrated Ecosystem Assessment
Date: September 3-4, 2014
Location: King Kamehameha's Kona Beach Hotel, Kailua Kona, Hawai'i
This symposium was held to present, discuss and share information on the state of Kailua Kona's marine ecosystem. The main focus of the group discussion activity was to develop indicators for ecosystem management. This report is focused on reporting the results of the group discussion activity.

Background

NOAA's Integrated Ecosystem Assessment

The Integrated Ecosystem Assessment employs ecosystem-based management to provide stakeholders with a complete understanding of interactions between the land and ocean. The IEA seeks to integrate biophysical and socio-economic aspects of an ecosystem and facilitate an effective management process by linking scientific information to stakeholder objectives. It recognizes humans as a key part of ecosystem processes, both by contributing to ecosystem stressors and by relying on ecosystem services.

A primary goal of an Integrated Ecosystem Assessment is to make scientific information available, understandable and operational for resource management. This is done for each region by developing a complete understanding of the ecosystem and interactions within every component.

DPSIR Conceptual Model

The Drivers-Pressures-State-Impact-Response (DPSIR) framework highlights the link between ecosystems and humans. The DPSIR model is recognized as a systems-thinking tool that can be used to clarify interactions between land and coastal habitats, identify all decision possibilities available to accomplish an objective, and illuminate the trade-offs that are associated with each possibility (Yee 2014). The framework of the DPSIR model forms relationships between ecosystem components and the responses to these components from stakeholders. The DPSIR model explains the natural and anthropogenic environmental drivers that create pressures on the ecosystem. These pressures change the state of the ecosystem which can have positive and negative socio-economic and biophysical impacts. In response to these impacts, stakeholders create policy and management decisions (Hohenthal 2014). It is also useful in identifying indicators of state change in an ecosystem. These indicators can then be used as proxies when measuring the progress of stakeholder objectives.

Group Discussion Activity

After completion of symposium presentations, a group discussion activity took place designed to collect community and expert knowledge to support the Kona Integrated Ecosystem Assessment. The activity was approximately two hours long and consisted of community members working in environmentally related fields, academia, and stakeholders. The main focus of the group activity was to develop potential indicators of the ecosystem state. Groups were asked to identify existing and potential threats to the ecosystem, and determine whether these threats are Drivers or Pressures.

Participants in the workshop first were asked to form groups based on their knowledge of North and South Kona. Each group had a facilitator and a note taker that would record the participant input. The groups were provided with a map of their focus region (North or South Kona), a large notepad, markers to write on the maps and notepad, and icons to label the map. The icons represented environmental drivers and pressures, and participants attached them to the map in appropriate areas with correlating scores. Each score represented the level of effect the icon has on the coral reef.

Group Discussion Activity

The group discussion activity had 33 participants from various organizations including, among others, University of Hawaii, The Kohala Center, NOAA, The Nature Conservancy, Department of Aquatic Resources, Four Seasons Hualalai Resort, and interested community members. The results of the group discussion activity have been summarized below.

Fishing Pressure

Fishing pressure was identified by all groups as very high in both the North and South. Intense fishing exists in Waikoloa, Puako, Kiholo, Kaupulehu, and Honaunau. Spear and shoreline fishing were given high values by groups two, four, five and six (group three did not list specific scores for fishing methods, but listed all fishing pressures with high scores). Spearfishing in Honaunau has undergone a dramatic increase, having a very large impact on the trevally population. Commercial fishing was listed as primarily occurring in the South. Aquarium fish collecting and Opihi harvesting is also high in South Point. Potential information on fishing pressure may reside in fishing tournament data (both charter boat and spearfishing). There is a lack of regulation in this area, and current fishing regulation does not protect large fish species. Future development and population increase will increase fishing pressure.

Ocean Activities

Ocean activities were mentioned by all groups as being a high source of pressure to the coral reefs. Tourism, snorkeling/scuba diving, and beach access had the highest score values. Beach recreation, yachts and surfing were also included, however the scores for these were much lower. The high tour boat industry, mainly in Kealakekua, is a large source of stress on dolphin populations and coral reefs according to group five.

Water Quality

Water quality is affected by sewage, nutrient input, urban sprawl, sedimentation and run-off. Data is lacking on accurate measurement of sewage input, but is a concern. Sewage sources include golf courses, cesspools, run-off, and the Honokohau treatment facility. Cesspools in Puako, coastal Honaunau and Manini beach also have little data to accurately understand their impact on water quality. Groups three and six listed urban sprawl as a contributing factor to poor water quality. Nutrient input was a moderate concern for all groups, although higher in the South than North. One source of nutrient input that was a concern was from cattle production, according to group five. Sedimentation is due to animal production, deforestation, cattle production (especially in the South), feral ungulates (pigs and goats), population growth and winds. There is a lower run-off and sedimentation worry in the South, according to group four.

However, sedimentation is very high due to volcanic ash, deforestation and off road vehicles according to group six.

Invasive Species

All groups listed invasive species as a current pressure to ecosystem function. Specifically, feral ungulates, near-shore plants, algae, roi (*Cephalopholis argus*) and crown of throwns (*Acanthaster planci)* were listed. Roi and crown of thorns were specifically mentioned by groups two, three, four and five. Group five specified that invasive near-shore plants, such as kiawe (*Prosopis pallida)*, are restructuring the near-shore habitat.

Environmental Drivers

Climate change impacts on coral reefs include sea level rise, erosion from sea level rise, ocean acidification and ocean temperature increasing. Coral disease is also increasing, according to the majority of groups. Other environmental factors include groundwater and freshwater input, storms, wave forcing, and ocean stratification. These were listed by group four with relatively low scores.

Potential Indicators

Each potential indicator was suggested during the group activity, and can be referenced either in the group notes or map photos.

Fishing indicators:

- Catch Per Unit Effort (CPUE)
- Fishery monitoring
- Fish catch sizes
- Spear-gun sales
- Recruitment surveys
- Use rate of boat ramps at small docks in South (Honaunau, Manini beach, Keahou)
- Cultural/subsistence fishing (both historically and present)
- Ratio: pel/dem; pisc/other
- Fish/Benthic surveys (disease, number, size)
- Presence/biomass of herbivores
- Microbial community

Tourism indicators:

- Number of people on public trails
- Number of cars in parking lots at public trails/beaches
- Number of dive tours in operation and daily tour statistics
- Number of tourists
- Kayak and snorkel gear rentals
- Hotel capacities
- Number of people/boat

Land based indicators:

- Population Growth
- Development
- Acreage of coffee farms

- Water clarity/turbidity
- Ungulate counts
- CPUE for pig hunt
- Tournaments
- Head of cattle of per area

Ocean based indicators:

- Algal growth (from nutrient pollution and reduced herbivore population)

Gaps in Knowledge

1. Historical cultural use of specific coral reefs may be a sign of historical coral reef health. Current cultural use may be more harmful to coral reef health than in the past, if population abundance is lower than historically. Using cultural use as an indicator may show where the healthiest reefs were/are.
2. Impacts of coffee production in the south on groundwater.
3. Submarine groundwater discharge possibly transporting pollutants to ocean.
4. The effects of county roads frequently being sprayed with Roundup and the effects of pesticides and urban chemicals in run-off.
5. Fishing activity could be monitored through shore observation, spawning guides, and community education.
6. Monitoring of aquarium fish landing to provide more accurate counts of aquarium fish take.
7. Agriculture permits, coffee farming information and data.

Recommendations

1. Schedule group discussions and activities mid-day (instead of at the end of the day) in order to maximize participants and enthusiasm.
2. Design group discussions and activities in such a way that will ensure that each group discusses the same topics. Each group can then have the potential to go further, but will have discussed the same core group of topics.

Possible Next Steps

- Send conceptual models to experts in the field in an effort to verify or correct the findings. Based on these responses, determine whether or not expert interview would be beneficial.
- Evaluate current products from group discussion to determine whether to further develop models (i.e. develop sub-models for individual indicators).
- Build a systems model based on DPSIR method
- Surveys on human preference and ecosystem service uses

Appendix B: HCC Workshop Report

Workshop Report for West Hawai‘i Integrated Ecosystem Assessment Program: Building Partnerships to Support Science and Management of West Hawai‘i's Marine Ecosystem
Date: August 3rd, 2015
Location: University of Hawai‘i at Hilo, Hilo, Hawai‘i
This workshop was held to continue the development of the West Hawaii DPSIR model. A focus was placed on understanding connections between identified social and ecological interactions. Additionally, key indicators that can be used to monitor the high priority interactions were evaluated.

Summary

There was a total number of 24 participants at the workshop, with a wide range of affiliations including Department of Aquatic Resources, UH Sea Grant, Conservation International Hawaii, The Nature Conservancy, NOAA, Coral Reef Alliance, watershed partnerships, students, and community members. The workshop was three hours long, with the activity lasting approximately 2.5 hours.

The objectives of the workshop included developing and verify the existing *drivers, pressures, ecosystem states, ecosystem services* and indicators for marine health. The interactions between pressures and four ecosystem states, and the interactions between drivers and select pressures were then identified and quantified. The direct effect of an ecosystem state onto ecosystem services were scored. Indicators were selected from a comprehensive list and groups determined where they would be appropriate for monitoring particular drivers or pressures.

After completing the workshop activity, participants were given the option to complete a survey. Based on the survey, the majority of participants increased their knowledge or gained a new skill from the workshop, as well as plan to use something learned from the workshop in their work. Approximately half of the workshop participants agreed that they would potentially use something learned from the workshop in their daily life. Approximately two-thirds of the participants agreed that they changed how they think about land-sea management based on their participation in the workshop. Every participant agreed that the DPSIR model and development process is useful for resource management in Hawaii.

Results of Activity

Note: The time frame for interactions was 1-5 years, however, this was not clarified with all groups.

Water Column

- This group changed the state name to Water Body because Water Column is referring to specific assemblage, whereas Water Body refers to chemical and biological structure.
- The highest weighted pressures (given a 4-5 score) that have a direct effect on the water column were ocean temperature, extreme events (e.g. hurricane, tsunami), nutrient input, pathogens, pharmaceuticals, hydrocarbons (e.g. motor oil), pesticides, and freshwater input. The pressures weighted as having some direct effect (given a 1-3 score) on the water column were sea level rise, ocean pH, sediments, other contaminants (e.g. bromine pools, sunscreen), habitat destruction, marine debris, human interaction with animals (this

pressure weighting was marked as uncertain), and extraction of fish. The pressures weighted as having no direct effect on the water column were coral disease, algal overgrowth, flooding, wind, and wave forcing.

- Proportionally, 40% of the water column is directly affected by four pressures: ocean temperature, nutrient input, pathogens, and pharmaceuticals (all ranked as 10% individually). 54% of the water column is directly affected by ten pressures ranked between 5-10%: sea level rise, ocean temperature, ocean pH, nutrient input, pathogens, pharmaceuticals, hydrocarbons, pesticides, extraction of fish, and freshwater input (surface and ground). The pressures ranked as 5% or below comprised the last 4%: extreme events, invasive species, precipitation, and lava.
- This group looked at driver interaction with two pressures: nutrient input and freshwater input. Nutrient input is influenced by land development and urban sprawl, resorts and golf courses, freshwater use and management, wastewater disposal systems, agriculture, animal production, feral ungulates, erosion, ocean dynamics, invasive species, and aquaculture. Freshwater input pressure is influenced by land development and urban sprawl, resorts and golf courses, freshwater use and management, wastewater disposal systems, agriculture, animal production, deforestation, feral ungulates, local climate, groundwater transport, and invasive species.
- The water column was weighted as having the strongest direct effect (a score of 5) on all ecosystem services.

Reef fishes

- The highest weighted pressures (given a 4-5 score) that have a direct effect on reef fishes were nutrient input, sediments, habitat destruction, and extraction of fish. The pressures weighted as having some direct effect (given a 1-3 score) on reef fishes were ocean temperature, ocean pH, extreme events, pathogens, marine debris, human interaction with animals, invasive species, coral disease, algal overgrowth, flooding, and freshwater input (surface and groundwater). The pressures weighted as having no direct effect on reef fishes were sea level rise, other contaminants, pharmaceuticals, hydrocarbons, pesticides, wind, wave forcing, precipitation, and lava.
- Proportionally, 50% of the reef fishes ecosystem state is directly affected by two pressures: habitat destruction and extraction of fish (ranked as 25% individually). 20% of the reef fishes ecosystem state is directly affected by nutrient input and sediments; each pressure ranked 10%. 15% of the reef fishes ecosystem state is directly affected by ocean temperature, extreme events, and flooding; each pressure ranked 5%. The pressures ranked below 5% included ocean pH, pathogens, marine debris, human interaction with animals, invasive species, coral disease, and algal overgrowth. (Note: The total proportion given by this group added to 94%.)
- This group looked at driver interaction with three pressures: nutrient input, sediments, and habitat destruction. Nutrient input is influenced by land development and urban sprawl, resorts and golf courses, freshwater use and management, wastewater disposal systems, agriculture, deforestation, feral ungulates, groundwater transport, and erosion. Sediment pressure is influenced by recreational land use, beach use, land development

and urban sprawl, resorts and golf courses, freshwater use and management, agriculture, animal production, deforestation, feral ungulates, erosion, ocean dynamics, and wind. Habitat destruction is influenced by boating and personal watercrafts, ocean tourism, recreational ocean use, beach use, non-commercial fishing, aquarium collection, commercial fishing, land development and urban sprawl, resorts and golf courses, freshwater use and management, wastewater disposal systems, agriculture, animal production, deforestation, feral ungulates, and erosion.

- The strongest direct effect on ecosystem services by reef fishes were on aquarium fish, aesthetic environment, non-extractive recreation, scientific research, education, cultural practices, heritage value, spiritual value, biological interactions, nutrient processing, biodiversity, and habitat. Ecosystem services that scored a 4 or lower were fish, shellfish, limu, shells, medicinal resources, biotechnology, existence, social interaction, climate regulation, atmospheric regulation, coastal protection.

Pelagic Fishes

- The highest weighted pressures (given a 4-5 score) that have a direct effect on the pelagic fishes ecosystem state were ocean temperature (due to early spawning), ocean pH (group was uncertain, but noted there is more a threat in the future and a need for more research), habitat destruction, and extraction of fish. The pressures weighted as having some direct effect (given a 1-3 score) on the pelagic fishes ecosystem state were extreme events, nutrient input, pathogens (with uncertainty), sediments, other contaminants, pharmaceuticals (high level of uncertainty), hydrocarbons, pesticides, marine debris, human interaction with animals, invasive species, coral disease, algal overgrowth, freshwater input (surface and groundwater), and wind. The pressures weighted as having no direct effect on the pelagic fishes ecosystem state were sea level rise, flooding, wave forcing, precipitation, and lava.
- Proportionally, 80% of the pelagic fishes ecosystem state is directly affected by three pressures: ocean temperature (20%), habitat destruction (25%), and extraction of fish (35%). 20% of the pelagic fishes ecosystem state is directly affected by ocean pH, nutrient input, pesticides, marine debris, human interaction with animals, and freshwater input. The following pressures ranked as less than 1%: extreme events, pathogens, sediments, other contaminants, pharmaceuticals, hydrocarbons, invasive species, coral disease, and algal overgrowth.
- This group looked at driver interaction with ocean temperature, habitat destruction, and extraction of fish. Ocean temperature is influenced by two drivers, local climate and ocean dynamics. Habitat destruction is influenced by five drivers: boating and personal watercrafts, ocean tourism, recreational ocean use, commercial fishing, and shipping. Extraction of fish is influenced by two drivers: non-commercial fishing and commercial fishing (including sport fishing).
- The largest direct effect (a score of 5) that the pelagic fishes ecosystem state has were on the ecosystem service fish, non-extractive recreation, cultural practices, heritage value, spiritual value, social interaction, biological interactions, and biodiversity. Ecosystem services that scored a 4 or lower were medicinal resources, biotechnology, non-food use

of fish, aesthetic environment, existence, scientific research, education, nutrient processing, and habitat.

Corals & Hardbottom

- The highest weighted pressures (given a 4-5 score) that have a direct effect on the corals and hardbottom ecosystem state were ocean temperature, extreme events, nutrient input, pesticides, habitat destruction, human interaction with animals (corals), extraction of fish, coral disease, algal overgrowth, wave forcing, injection wells, cess pools and septic tanks, and boat damage to reefs. The pressures weighted as having some direct effect (given a 1-3 score) on the corals and hardbottom ecosystem state were sea level rise, ocean pH, sediments, other contaminants, hydrocarbons, invasive species, flooding, freshwater input (surface and groundwater), wind, and currents. The pressures weighted as having no direct effect on the corals and hardbottom ecosystem state were pharmaceuticals, precipitation, and lava.
- This group did not have time to complete the portion of the activity linking driver influence to pressures.
- All ecosystem services were weighted the strongest direct effect (a score of 5) except for limu (3), medicinal resources (4), biotechnology resources (4), climate regulation (2), and atmospheric regulation (1).

Recommendations

Future workshops would benefit from reorganizing activities so that they are shorter in length of time and involve fewer steps to complete, making it easier to follow the process. In opening presentation, showing more examples of how the DPSIR process is effectively improving management would be beneficial. Also, underlining the importance of involving the community during this process would demonstrate the importance of the workshop.

Before beginning the activity, participants should discuss the DPSIR process as a group to ensure everyone understands the language being used. Facilitators of the activities should go through a mock version with the workshop team to ensure they understand the process and goals. The timeline must also be defined before beginning activity (1-5 years).

Facilitator feedback:
Things that ran smoothly:

- group formation - participators easily formed into focus groups
- incorporation of diverse viewpoints and ideas with no conflicts and participation was evident from all members, the structure provided an environment were participants felt comfortable sharing
- there were many "aha" moments were participants were surprised at what they documented as the drivers that had the most impact on the goods and services

Things that need improvement:

- The data that you wanted to record was too long-participants lost focus by the third form/poster
- Recording methods were confusing - percentages, arrows, weights... and were to record this information on the sheet/poster

- It got messy. I don't know how you can read and interpret it.

Suggestions:

- spend more time on going over exactly how to record the information
- break it down into more manageable pieces
- hold workshops or spend more time training facilitators so they can keep the group focused and record the necessary information with less support from you during the workshop

Next steps

- Hold similar workshop, with necessary improvements, in Kona, Hawai‘i, so local residents have an opportunity to participate.
- Expert interviews can be used to complete the more obscure ecosystem state models, such as, anchialine ponds, cetaceans, and turtles.
- The pressures that were rated the highest could be used in a survey modeled after Cook et al. 2014. (Alternatively, the pressures could be indexed, however some participants noted that the separation of related pressures was helpful in weighting interactions.)

Answers to survey examples:

I increased my knowledge or gained a new skill from today's workshop.

Examples:

learned new indicators for reef health

conversations gave me new tidbits of info on reef fish topics

description of commercial fishing

different perspectives

learned about commercial/non-commercial patterns from community member

Importance of indicators for scientific research and greater understanding of marine ecosystems

some ocean terms

seeing the process of model development

I plan on using information that I learned today in my work.

Examples:

I create authentic research projects for students and can use this model to facilitate classroom discussion

prevalence and use of commercial landings

sparking these conversations with the communities I work with

linking ocean tourism with pelagic fishes

currently an environmental studies student but this information is important for increasing my understanding

global change class, project development

I plan on using information that I learned today in my daily life.

Examples:
Don't cover this as much on day-to-day basis
share with friends
better understand of West Hawaii
may be used in my studies for the upcoming school year
not sure

I changed how I think about land-sea management based on today's workshop.

Examples:
good discussion
some new ideas and perspectives
I realized there are many aspects for land-sea mgmt to look over
knew it was complicated

It's useful for starting conversation or identifying research needed, but a meta-analysis of research would be useful as a starting place. It felt we were debating out feelings or opinions about a problem and not using research data to identify causes of a problem

I think the DPSIR model and process is useful for resource management in Hawaii.
Examples:
if digital
Helpful in identifying inter-related causes
Gets at the importance of species/resources
good to link/show relationships of ecosystems
The process is the key- engaging community- come to West Hawaii and let Makaʻala share about ? Model in Hanalei
It is easy to understand and effectively displays ecosystem interactions
useful and can be adapted to different communities

Additional Comments:

It would be helpful to have exampes of which pelagic fish species we are most interested in discussing. Also some sort of scale to record the level of certainty on different pressures. Some "pressures" have a more well established body of literature than other pressures.

Mahalo! Great activity
LMK how I can help [take wksp to W. Hawaii]
Great workshop- another good opportunity to meet people and work together

Appendix C: Electronic Survey Materials

Invitation Emails
Sent out: 5/29/2016

Aloha,

I would like to invite you to participate in a short 20-minute survey that aims to assess how natural environmental changes and human activities shape West Hawaiʻi's marine ecosystem. You are being invited because you have extensive experience and knowledge about the marine ecosystem in West Hawaiʻi.

For those who don't know me, I am a graduate student at UH Manoa in the Department of Natural Resources and Environmental Management, working under advisor Dr. Kirsten Oleson. I am coordinating my research with Dr. Jamison Gove and the West Hawaiʻi Integrated Ecosystem Assessment (IEA) to create conceptual models representing the West Hawaiʻi marine ecosystem.

This survey builds upon information collected at two previous West Hawaiʻi IEA workshops: the Symposium on West Hawaiʻi's marine ecosystem held in Kailua-Kona in September 2014, and a workshop held in conjunction with the Hawaiʻi Conservation Conference held in Hilo in August 2015. The survey contains multiple sections that examine specific aspects of West Hawaiʻi's marine ecosystem (i.e., corals, the water body, pelagic fishes, and reef fishes). The overarching goals of this survey are to identify stressors and influences on the marine ecosystem state and to understand community benefits and values derived from the region's natural environment.

I would like to request your participation by June 10th, 2016. Your input directly supports the West Hawaiʻi IEA in addressing current and future resource management questions in this region. Thank you in advance for taking the time and helping to expand our understanding of West Hawaiʻi's marine ecosystem.

The following link will take you to the survey website:
(Link no longer active)

Mahalo nui,
Rebecca Ingram
MS Candidate
Natural Resources & Environmental Mgmt.
University of Hawaiʻi at Mānoa

Sent on 6/13/16

Aloha,
This is a reminder about **your invitation to participate in my survey on West Hawaiʻi's marine ecosystem**. Your input directly supports the West Hawaiʻi Integrated Ecosystem

Assessment, as well as future research and management in the region. Your input is also **a critical component of my MS thesis research**.

My thesis focuses on creating conceptual ecosystem models for West Hawaiʻi's coastal and marine ecosystems. **My models rely on your knowledge and expertise in order to create an accurate representation of the system**. Participants in an upcoming community workshop in Kona will use these models as the basis for in-depth discussions about current threats and management options.

Thank you all very much for your valuable time and expertise. **Please respond by Friday, June 17th**. The following link will take you to the survey website:

(Link no longer active)

Mahalo,

Rebecca Ingram
MS Candidate
Natural Resources & Environmental Mgmt.
University of Hawaiʻi at Mānoa

Copy of Electronic Survey

West Hawaiʻi Survey – Blank Copy

QX University of Hawaiʻi Consent to Participate in Research Survey
The West Hawaiʻi Integrated Ecosystem Assessment Program: Building Partnerships to Support Science and Management of West Hawaiʻi's Marine Ecosystem
The overall purpose of this research is to develop a deeper understanding of West Hawaiʻi's marine ecosystem by identifying social and ecological interactions between the land and ocean in support of ecosystem-based management. This work directly supports NOAA's West Hawaiʻi Integrated Ecosystem Assessment. This research aims to understand ecosystem threats that exist in West Hawaiʻi and how they interact and influence the ecosystem.   Project Description - Activities and Time Commitment: If you participate in this survey, you will be invited to answer all questions. The survey should take between 20 – 60 minutes, depending on the extent of your knowledge on the topic.   Benefits and Risks: There will be no direct benefit to you for participating in this survey. However, your participation will help improve our understanding of social and ecological components of the West Hawaiʻi marine ecosystem.   Confidentiality and Privacy: All data collected from this survey will be kept in a secure location. Only those directly related to this research project will have access to the raw data, although legally authorized agencies, including the University of Hawaiʻi Human Studies Program, have the right to review research records. If you would like a summary of the findings, please contact the number listed near the end of this consent form.   Voluntary Participation: Participation in this survey is voluntary. In addition, at any point during this survey, you can withdraw your permission without any penalty or loss of benefits.   Questions: If you have any questions about this

research, please feel free to contact the graduate student researcher via e-mail at ingramr@hawaii.edu. If you have any questions about your rights as a participant in this research, you can contact the University of Hawaiʻi, Human Studies Program, by phone at (808) 956-5007 or by e-mail at uhirb@hawaii.edu. If you agree to participate in this research by taking this survey, please sign below.

Signature of Consent:
Date:

Q1 Survey Part 1: Reef Fishes
Reef fishes are affected by many pressures. These pressures can be caused by socio-economic and natural drivers. Drivers are the natural or societal processes or events that cause a change in the level of a pressure. What drivers are creating pressures on the reef fishes in West Hawaiʻi?

- ❑ I do not know enough about reef fishes in West Hawaiʻi to answer this section of the survey. (Checking this will skip to the next section of survey.)
- ❑ boating/personal watercrafts
- ❑ ocean tourism (dolphin or Manta tours)
- ❑ recreational land use (off road vehicles, dirt biking, hunting)
- ❑ recreational ocean use (surfing, kayaking, SCUBA diving, snorkeling, free diving)
- ❑ beach use
- ❑ non-commercial fishing (spear, net, line)
- ❑ aquarium fish collection
- ❑ commercial fishing
- ❑ land development & urban sprawl
- ❑ resorts & golf courses
- ❑ freshwater use & management
- ❑ wastewater disposal systems
- ❑ agriculture
- ❑ animal production
- ❑ deforestation
- ❑ feral ungulates (goats, pigs, deer)
- ❑ local climate
- ❑ groundwater transport
- ❑ erosion
- ❑ ocean dynamics (currents and mixing)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q2 Survey Part 1: Reef Fishes
In the next four questions you will identify what pressures (the direct cause of change) are created by the drivers you just identified. Pressures have been divided into categories to facilitate the survey format, but we recognize some pressures belong in multiple categories. Which (if any) human-use derived pressures on reef fishes in West Hawaiʻi are caused by the drivers you identified?

Q3 Survey Part 1: Reef Fishes
Which (if any) pollution related pressures on reef fishes in West Hawaiʻi are caused by the drivers you identified?

Q4 Survey Part 1: Reef Fishes
Which (if any) biological pressures on reef fishes in West Hawaiʻi are caused by the drivers you identified?

Q5 Survey Part 1: Reef Fishes
Which (if any) climate and ocean related pressures on reef fishes in West Hawaiʻi are caused by the drivers you identified?

Q6 Survey Part 1: Reef Fishes
This survey focuses on four particular components of the ecosystem: reef fishes, corals and hard-bottom, pelagic fishes, and the water body. The ecosystem state is defined by its physical, chemical, and biological characteristics. The state of one ecosystem component can affect the state of another. Does the state of this component (reef fishes) affect, or is it affected by, the state of these other components in the West Hawaiʻi ecosystem? Select those that apply.

- ❑ corals and hard-bottom (corals, calcium carbonate built structures, and hard substrate)
- ❑ pelagic fishes (fishes who live around and/or beyond the reef habitat)
- ❑ water body (physical, chemical, and biological composition of the water body)
- ❑ turtles
- ❑ cetaceans (dolphins and whales residing or migrating through West Hawaiʻi)
- ❑ beaches (sandy shorelines)
- ❑ anchialine ponds (enclosed water body or pond with underground connection to the ocean)
- ❑ Other ____________________

Q7 Survey Part 1: Reef Fishes
We are working to understand the multiple ways that people are impacted by changes in ecosystem states. What services, goods, benefits, and/or values do you think reef fishes provide to you or the West Hawaiʻi community?

- ❑ fish, shellfish, limu (safe to consume seafood)
- ❑ aquarium fish (fish collected for aquariums)
- ❑ shells (material for jewelry, display, ceremony)
- ❑ medicinal resources (material for treatments/aid)
- ❑ biotechnology resources (resources for producing or modifying products)
- ❑ transport infrastructure (ecosystems provide the means of transportation of people and goods)
- ❑ biodiversity (existence of species richness and genetic diversity)
- ❑ habitat (existence of area to support species)
- ❑ nutrient cycling (the exchange of nutrients within ecosystem)
- ❑ biological interactions (species interactions that support/continue/provide valuable ecosystem functions)
- ❑ climate regulation (influence of ecological processes on temperature, wind, precipitation, and evaporation)
- ❑ atmospheric regulation (exchange gases, such as CO2 and O2, with atmosphere)
- ❑ water purification (ecosystem processes that filter out and decompose organic waste)
- ❑ coastal protection (provide protection against waves or storms)
- ❑ aesthetic environment (visually valuable or beneficial)
- ❑ existence (benefit people receive from knowing that a place or animal exists)
- ❑ non extractive recreation (activities that require particular places and/or animals)
- ❑ scientific research (opportunity to conduct studies)
- ❑ education (provides opportunity for learning, formally or informally)
- ❑ Hawaiian cultural value (ecosystems or species valuable for perpetuation of native Hawaiian culture)
- ❑ heritage value (historically or culturally valuable ecosystems or species)
- ❑ spiritual value (spiritual and religious values associated with ecosystems or species)
- ❑ social interaction (provides opportunity for community or family gatherings, events, and relationships)
- ❑ inspiration value (ecosystem or species provides inspiration for art, folklore, architecture)
- ❑ sense of place (ecosystems provide people with opportunity to cultivate a sense of belonging, commitment, identity, and community)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q8 Survey Part 1: Reef Fishes
Do you have any additional comments or questions regarding this section of the survey?

Q9 Survey Part 2: Corals & Hard-Bottom
Corals and hard-bottom areas (calcium carbonate built structures, and hard substrate) are affected by many pressures. These pressures can be caused by socio-economic and natural drivers. Drivers are natural or societal processes or events that cause a change in the level of a pressure. What drivers are creating pressures on coral and hard-bottom areas in West Hawaiʻi?

- ❑ I do not know enough about corals and hard-bottom in West Hawai‘i to answer this section of the survey. (Checking this will skip to the next section of survey.)
- ❑ boating/personal watercrafts
- ❑ ocean tourism (dolphin or Manta tours)
- ❑ recreational land use (off road vehicles, dirt biking, hunting)
- ❑ recreational ocean use (surfing, kayaking, SCUBA diving, snorkeling, free diving)
- ❑ beach use
- ❑ non-commercial fishing (spear, net, line)
- ❑ aquarium fish collection
- ❑ commercial fishing
- ❑ land development & urban sprawl
- ❑ resorts & golf courses
- ❑ freshwater use & management
- ❑ wastewater disposal systems
- ❑ agriculture
- ❑ animal production
- ❑ deforestation
- ❑ feral ungulates (goats, pigs, deer)
- ❑ local climate
- ❑ groundwater transport
- ❑ erosion
- ❑ ocean dynamics (currents and mixing)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q10 Survey Part 2: Corals & Hard-Bottom
In the next four questions you will identify what pressures (the direct cause of change) are created by the drivers you just identified. Pressures have been divided into categories to facilitate the survey format, but we recognize some pressures belong in multiple categories. Which (if any) human-use derived pressures on corals and hard-bottom in West Hawaiʻi are caused by the drivers you identified?

Q11 Survey Part 2: Corals & Hard-Bottom
Which (if any) pollution related pressures on corals and hard-bottom areas in West Hawaiʻi are caused by the drivers you identified?

Q12 Survey Part 2: Corals & Hard-Bottom
Which (if any) biological pressures on corals and hard-bottom areas in West Hawaiʻi are caused by the drivers you identified?

Q13 Survey Part 2: Corals & Hard-Bottom
Which (if any) climate and ocean related pressures on corals and hard-bottom areas in West Hawaiʻi are caused by the drivers you identified?

Q14 Survey Part 2: Corals & Hard-Bottom
This survey focuses on four particular components of the ecosystem: reef fishes, corals and hard-bottom, pelagic fishes, and the water body. The ecosystem state is defined by its physical, chemical, and biological characteristics. The state of one ecosystem component can affect the state of another. Does the state of this component (corals & hard-bottom) affect, or is it affected by, the state of these other components in the West Hawaiʻi ecosystem? Select those that apply.

- ❑ reef fishes (fishes that live primarily in the coral reef habitat)
- ❑ pelagic fishes (fishes who live around and/or beyond the reef habitat)
- ❑ water body (physical, chemical, and biological composition of the water body)
- ❑ turtles
- ❑ cetaceans (dolphins and whales residing or migrating through West Hawaiʻi)
- ❑ beaches (sandy shorelines)
- ❑ anchialine ponds (enclosed water body or pond with underground connection to the ocean)
- ❑ Other ____________________
- ❑ Other ____________________
- ❑ Other ____________________

Q15 Survey Part 2: Corals & Hard-Bottom
We are working to understand the multiple ways that people are impacted by changes in ecosystem states. What services, goods, benefits, and/or values do you think corals and hard-bottom areas provide to you or the West Hawaiʻi community?

- ❑ fish, shellfish, limu (safe to consume seafood)
- ❑ aquarium fish (fish collected for aquariums)
- ❑ shells (material for jewelry, display, ceremony)
- ❑ medicinal resources (material for treatments/aid)
- ❑ biotechnology resources (resources for producing or modifying products)
- ❑ transport infrastructure (ecosystems provide the means of transportation of people and goods)
- ❑ biodiversity (existence of species richness and genetic diversity)
- ❑ habitat (existence of area to support species)
- ❑ nutrient cycling (the exchange of nutrients within ecosystem)
- ❑ biological interactions (species interactions that support/continue/provide valuable ecosystem functions)
- ❑ climate regulation (influence of ecological processes on temperature, wind, precipitation, and evaporation)
- ❑ atmospheric regulation (exchange gases, such as CO2 and O2, with atmosphere)
- ❑ water purification (ecosystem processes that filter out and decompose organic waste)
- ❑ coastal protection (provide protection against waves or storms)
- ❑ aesthetic environment (visually valuable or beneficial)
- ❑ existence (benefit people receive from knowing that a place or animal exists)
- ❑ non extractive recreation (activities that require particular places and/or animals)
- ❑ scientific research (opportunity to conduct studies)
- ❑ education (provides opportunity for learning, formally or informally)
- ❑ Hawaiian cultural value (ecosystems or species valuable for perpetuation of native Hawaiian culture)
- ❑ heritage value (historically or culturally valuable ecosystems or species)
- ❑ spiritual value (spiritual and religious values associated with ecosystems or species)
- ❑ social interaction (provides opportunity for community or family gatherings, events, and relationships)
- ❑ inspiration value (ecosystem or species provides inspiration for art, folklore, architecture)
- ❑ sense of place (ecosystems provide people with opportunity to cultivate a sense of belonging, commitment, identity, and community)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q16 Survey Part 2: Corals & Hard-Bottom
Do you have any additional comments or questions regarding this section of the survey?

Q17 Survey Part 3: Pelagic Fishes
Pelagic fishes are affected by many pressures. These pressures can be caused by socio-economic and natural drivers. Drivers are natural or societal processes or events that cause a change in the level of a pressure. What drivers are creating pressures on pelagic fishes in West Hawai‘i?

- ❑ I do not know enough about pelagic fishes in West Hawaiʻi to answer this section of the survey. (Checking this will skip to the next section of survey.)
- ❑ boating/personal watercrafts
- ❑ ocean tourism (dolphin or Manta tours)
- ❑ recreational land use (off road vehicles, dirt biking, hunting)
- ❑ recreational ocean use (surfing, kayaking, SCUBA diving, snorkeling, free diving)
- ❑ beach use
- ❑ non-commercial fishing (spear, net, line)
- ❑ aquarium fish collection
- ❑ commercial fishing
- ❑ land development & urban sprawl
- ❑ resorts & golf courses
- ❑ freshwater use & management
- ❑ wastewater disposal systems
- ❑ agriculture
- ❑ animal production
- ❑ deforestation
- ❑ feral ungulates (goats, pigs, deer)
- ❑ local climate
- ❑ groundwater transport
- ❑ erosion
- ❑ ocean dynamics (currents and mixing)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q18 Survey Part 3: Pelagic Fishes
In the next four questions you will identify what pressures (the direct cause of change) are created by the drivers you just identified. Pressures have been divided into categories to facilitate the survey format, but we recognize some pressures belong in multiple categories. Which (if any) human-use derived pressures on pelagic fishes in West Hawaiʻi are caused by the drivers you identified?

Q19 Survey Part 3: Pelagic Fishes
Which (if any) pollution related pressures on pelagic fishes in West Hawaiʻi are caused by the drivers you identified?

Q20 Survey Part 3: Pelagic Fishes
Which (if any) biological pressures on pelagic fishes in West Hawaiʻi are caused by the drivers you identified?

Q21 Survey Part 3: Pelagic Fishes
Which (if any) climate and ocean related pressures on pelagic fishes in West Hawaiʻi are caused by the drivers you identified?

Q22 Survey Part 3: Pelagic Fishes
This survey focuses on four particular components of the ecosystem: reef fishes, corals and hard-bottom, pelagic fishes, and the water body. The ecosystem state is defined by its physical, chemical, and biological characteristics. The state of one ecosystem component can affect the state of another. Does the state of this component (pelagic fishes) affect, or is it affected by, the state of these other components in the West Hawaiʻi ecosystem? Select those that apply.

- ❑ reef fishes (fishes that live primarily in the coral reef habitat)
- ❑ corals and hard-bottom (corals, calcium carbonate built structures, and hard substrate)
- ❑ water body (physical, chemical, and biological composition of the water body)
- ❑ turtles
- ❑ cetaceans (dolphins and whales residing or migrating through West Hawaiʻi)
- ❑ beaches (sandy shorelines)
- ❑ anchialine ponds (enclosed water body or pond with underground connection to the ocean)
- ❑ Other ____________________
- ❑ Other ____________________
- ❑ Other ____________________

Q23 Survey Part 3: Pelagic Fishes
We are working to understand the multiple ways that people are impacted by changes in ecosystem states. What services, goods, benefits, and/or values do you think pelagic fishes provide to you or the West Hawaiʻi community?

- ❑ fish, shellfish, limu (safe to consume seafood)
- ❑ aquarium fish (fish collected for aquariums)
- ❑ shells (material for jewelry, display, ceremony)
- ❑ medicinal resources (material for treatments/aid)
- ❑ biotechnology resources (resources for producing or modifying products)
- ❑ transport infrastructure (ecosystems provide the means of transportation of people and goods)
- ❑ biodiversity (existence of species richness and genetic diversity)
- ❑ habitat (existence of area to support species)
- ❑ nutrient cycling (the exchange of nutrients within ecosystem)
- ❑ biological interactions (species interactions that support/continue/provide valuable ecosystem functions)
- ❑ climate regulation (influence of ecological processes on temperature, wind, precipitation, and evaporation)
- ❑ atmospheric regulation (exchange gases, such as CO_2 and O_2, with atmosphere)
- ❑ water purification (ecosystem processes that filter out and decompose organic waste)
- ❑ coastal protection (provide protection against waves or storms)
- ❑ aesthetic environment (visually valuable or beneficial)
- ❑ existence (benefit people receive from knowing that a place or animal exists)
- ❑ non extractive recreation (activities that require particular places and/or animals)
- ❑ scientific research (opportunity to conduct studies)
- ❑ education (provides opportunity for learning, formally or informally)
- ❑ Hawaiian cultural value (ecosystems or species valuable for perpetuation of native Hawaiian culture)
- ❑ heritage value (historically or culturally valuable ecosystems or species)
- ❑ spiritual value (spiritual and religious values associated with ecosystems or species)
- ❑ social interaction (provides opportunity for community or family gatherings, events, and relationships)
- ❑ inspiration value (ecosystem or species provides inspiration for art, folklore, architecture)
- ❑ sense of place (ecosystems provide people with opportunity to cultivate a sense of belonging, commitment, identity, and community)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q24 Survey Part 3: Pelagic Fishes
Do you have any additional comments or questions regarding this section of the survey?

Q25 Survey Part 4: Water Body
The water body is affected by many pressures. These pressures can be caused by socio-economic and natural drivers. Drivers are natural or societal processes or events that create or change the level of a pressure. What drivers are creating pressures on the water body in West Hawaiʻi?

- ❑ I do not know enough about reef fishes in West Hawai‘i to answer this section of the survey. (Checking this will skip to the next section of survey.)
- ❑ boating/personal watercrafts
- ❑ ocean tourism (dolphin or Manta tours)
- ❑ recreational land use (off road vehicles, dirt biking, hunting)
- ❑ recreational ocean use (surfing, kayaking, SCUBA diving, snorkeling, free diving)
- ❑ beach use
- ❑ non-commercial fishing (spear, net, line)
- ❑ aquarium fish collection
- ❑ commercial fishing
- ❑ land development & urban sprawl
- ❑ resorts & golf courses
- ❑ freshwater use & management
- ❑ wastewater disposal systems
- ❑ agriculture
- ❑ animal production
- ❑ deforestation
- ❑ feral ungulates (goats, pigs, deer)
- ❑ local climate
- ❑ groundwater transport
- ❑ erosion
- ❑ ocean dynamics (currents and mixing)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q26 Survey Part 4: Water Body
In the next four questions you will identify what pressures (the direct cause of change) are created by the drivers you just identified. Pressures have been divided into categories to facilitate the survey format, but we recognize that some pressures belong in multiple categories. Which (if any) human-use derived pressures on the water body in West Hawaiʻi are caused by the drivers you identified?

Q27 Survey Part 4: Water Body
Which (if any) pollution related pressures on the water body in West Hawaiʻi are caused by the drivers you identified?

Q28 Survey Part 4: Water Body
Which (if any) biological pressures on that water body in West Hawaiʻi are caused by the drivers you identified?

Q29 Survey Part 4: Water Body
Which (if any) climate and ocean related pressures on the water body in West Hawaiʻi are caused by the drivers you identified?

Q30 Survey Part 4: Water Body
This survey focuses on four particular components of the ecosystem: reef fishes, corals and hard-bottom, pelagic fishes, and the water body. The ecosystem state is defined by its physical, chemical, and biological characteristics. The state of one ecosystem component can affect the state of another. Does the state of this component (water body) affect, or is it affected by, the state of these other components in the West Hawaiʻi ecosystem? Select those that apply.

- ❑ reef fishes (fishes that live primarily in the coral reef habitat)
- ❑ corals and hard-bottom (corals, calcium carbonate built structures, and hard substrate)
- ❑ pelagic fishes (fishes that live around and/or beyond the reef habitat)
- ❑ turtles
- ❑ cetaceans (dolphins and whales residing or migrating through West Hawaiʻi)
- ❑ beaches (sandy shorelines)
- ❑ anchialine ponds (enclosed water body or pond with underground connection to the ocean)
- ❑ Other ____________________
- ❑ Other ____________________
- ❑ Other ____________________

Q31 Survey Part 4: Water Body
We are working to understand the multiple ways that people are impacted by changes in ecosystem states. What services, goods, benefits, and/or values do you think the water body provide to you or the West Hawaiʻi community?

- ❑ fish, shellfish, limu (safe to consume seafood)
- ❑ aquarium fish (fish collected for aquariums)
- ❑ shells (material for jewelry, display, ceremony)
- ❑ medicinal resources (material for treatments/aid)
- ❑ biotechnology resources (resources for producing or modifying products)
- ❑ transport infrastructure (ecosystems provide the means of transportation of people and goods)
- ❑ biodiversity (existence of species richness and genetic diversity)
- ❑ habitat (existence of area to support species)
- ❑ nutrient cycling (the exchange of nutrients within ecosystem)
- ❑ biological interactions (species interactions that support/continue/provide valuable ecosystem functions)
- ❑ climate regulation (influence of ecological processes on temperature, wind, precipitation, and evaporation)
- ❑ atmospheric regulation (exchange gases, such as CO_2 and O_2, with atmosphere)
- ❑ water purification (ecosystem processes that filter out and decompose organic waste)
- ❑ coastal protection (provide protection against waves or storms)
- ❑ aesthetic environment (visually valuable or beneficial)
- ❑ existence (benefit people receive from knowing that a place or animal exists)
- ❑ non extractive recreation (activities that require particular places and/or animals)
- ❑ scientific research (opportunity to conduct studies)
- ❑ education (provides opportunity for learning, formally or informally)
- ❑ Hawaiian cultural value (ecosystems or species valuable for perpetuation of native Hawaiian culture)
- ❑ heritage value (historically or culturally valuable ecosystems or species)
- ❑ spiritual value (spiritual and religious values associated with ecosystems or species)
- ❑ social interaction (provides opportunity for community or family gatherings, events, and relationships)
- ❑ inspiration value (ecosystem or species provides inspiration for art, folklore, architecture)
- ❑ sense of place (ecosystems provide people with opportunity to cultivate a sense of belonging, commitment, identity, and community)
- ❑ other: ____________________
- ❑ other: ____________________
- ❑ other: ____________________

Q32 Survey Part 4: Water Body
Do you have any additional comments or questions regarding this section of the survey?

Q32 Do you have any additional information or comments you would like to add before finishing this survey? (Note: Clicking to the next button will finish the survey, and you will no longer be able to go back and edit previous questions.)

Interactions Identified Through Electronic Survey

Corals and Hard-Bottom

Specific Type	Type
beach use	driver
recreational ocean use	driver
boating / personal watercrafts	driver
freshwater use & management	driver
aquarium fish collection	driver
agriculture	driver
groundwater transport	driver
erosion	driver
ocean dynamics	driver
animal production	driver
commercial fishing	driver
deforestation	driver
feral ungulates	driver
land development & urban sprawl	driver
local climate	driver
non-commercial fishing	driver
ocean tourism	driver
recreational land use	driver
resorts & golf courses	driver
wastewater disposal systems	driver
aesthetic environment	**impacted ecosystem service**
aquarium fish	**impacted ecosystem service**
atmospheric regulation	**impacted ecosystem service**
biodiversity	**impacted ecosystem service**
biological Interactions	**impacted ecosystem service**
biotechnology resources	**impacted ecosystem service**
climate regulation	**impacted ecosystem service**
coastal protection	**impacted ecosystem service**
education	**impacted ecosystem service**
existence	**impacted ecosystem service**
fish, shellfish, limu	**impacted ecosystem service**
habitat	**impacted ecosystem service**
Hawaiian cultural value	**impacted ecosystem service**
heritage value	**impacted ecosystem service**
inspirational value	impacted ecosystem service
medicinal resources	**impacted ecosystem service**
non-extractive recreation	**impacted ecosystem service**
nutrient cycling	**impacted ecosystem service**
scientific research	**impacted ecosystem service**
sense of place	impacted ecosystem service
shells	**impacted ecosystem service**
social Interaction	**impacted ecosystem service**
spiritual value	**impacted ecosystem service**
transport infrastructure	impacted ecosystem service
water purification	impacted ecosystem service
algal overgrowth	**pressure**
coral disease	**pressure**
coral physical damage	pressure
currents	**pressure**

extraction of fish	**pressure**
extreme events	**pressure**
flooding	**pressure**
freshwater input	**pressure**
habitat destruction	**pressure**
human disturbance to animals	**pressure**
hydrocarbons	**pressure**
marine debris	**pressure**
non-native invasive species	**pressure**
nutrient input	**pressure**
ocean pH	**pressure**
ocean temperature	**pressure**
other contaminants (sunscreen)	**pressure**
pesticides	**pressure**
sea level rise	**pressure**
sediments	**pressure**
wave forcing	**pressure**
wind	**pressure**
pathogens	*pressure*
boat damage	*pressure*
cesspools & septic	*pressure*
injection wells	*pressure*
pelagic fishes	ecosystem state
water body	ecosystem state
turtles	ecosystem state
cetaceans	ecosystem state
beaches	ecosystem state
anchialine ponds	ecosystem state
reef fishes	ecosystem state

bold = identified at HCC and in survey	42
regular = identified only in survey	32
italics = identified at HCC and not in survey	4

Corals and Hard-Bottom

From	To	Interaction Description
agriculture	algal overgrowth	driver - pressure
agriculture	coral disease	driver - pressure
agriculture	currents	driver - pressure
agriculture	extraction of fish	driver - pressure
agriculture	extreme events	driver - pressure
agriculture	flooding	driver - pressure
agriculture	freshwater input	driver - pressure
agriculture	habitat destruction	driver - pressure
agriculture	human disturbance to animals	driver - pressure
agriculture	hydrocarbons	driver - pressure
agriculture	marine debris	driver - pressure
agriculture	non-native invasive species	driver - pressure
agriculture	nutrient input	driver - pressure

agriculture	ocean pH	driver - pressure
agriculture	ocean temperature	driver - pressure
agriculture	other contaminants (sunscreen)	driver - pressure
agriculture	pesticides	driver - pressure
agriculture	sea level rise	driver - pressure
agriculture	sediments	driver - pressure
agriculture	wave forcing	driver - pressure
agriculture	wind	driver - pressure
animal production	algal overgrowth	driver - pressure
animal production	coral disease	driver - pressure
animal production	currents	driver - pressure
animal production	extreme events	driver - pressure
animal production	flooding	driver - pressure
animal production	freshwater input	driver - pressure
animal production	habitat destruction	driver - pressure
animal production	hydrocarbons	driver - pressure
animal production	marine debris	driver - pressure
animal production	non-native invasive species	driver - pressure
animal production	nutrient input	driver - pressure
animal production	ocean pH	driver - pressure
animal production	ocean temperature	driver - pressure
animal production	other contaminants (sunscreen)	driver - pressure
animal production	pesticides	driver - pressure
animal production	sediments	driver - pressure
animal production	wave forcing	driver - pressure
animal production	wind	driver - pressure
aquarium fish collection	algal overgrowth	driver - pressure
aquarium fish collection	coral disease	driver - pressure
aquarium fish collection	extraction of fish	driver - pressure
aquarium fish collection	extreme events	driver - pressure
aquarium fish collection	habitat destruction	driver - pressure
aquarium fish collection	human disturbance to animals	driver - pressure
aquarium fish collection	marine debris	driver - pressure
aquarium fish collection	non-native invasive species	driver - pressure
aquarium fish collection	other contaminants (sunscreen)	driver - pressure
beach use	habitat destruction	driver - pressure
beach use	human disturbance to animals	driver - pressure
beach use	non-native invasive species	driver - pressure
beach use	other contaminants (sunscreen)	driver - pressure
boating / personal watercrafts	coral physical damage	driver - pressure
boating / personal watercrafts	habitat destruction	driver - pressure

boating / personal watercrafts	human disturbance to animals	driver - pressure
boating / personal watercrafts	hydrocarbons	driver - pressure
boating / personal watercrafts	other contaminants (sunscreen)	driver - pressure
commercial fishing	algal overgrowth	driver - pressure
commercial fishing	coral disease	driver - pressure
commercial fishing	extraction of fish	driver - pressure
commercial fishing	extreme events	driver - pressure
commercial fishing	habitat destruction	driver - pressure
commercial fishing	human disturbance to animals	driver - pressure
commercial fishing	marine debris	driver - pressure
commercial fishing	non-native invasive species	driver - pressure
commercial fishing	other contaminants (sunscreen)	driver - pressure
corals and hard-bottom	aesthetic environment	state - ecosystem service
corals and hard-bottom	anchialine ponds	state - state
corals and hard-bottom	aquarium fish	state - ecosystem service
corals and hard-bottom	atmospheric regulation	state - ecosystem service
corals and hard-bottom	beaches	state - state
corals and hard-bottom	biodiversity	state - ecosystem service
corals and hard-bottom	biological interactions	state - ecosystem service
corals and hard-bottom	biotechnology resources	state - ecosystem service
corals and hard-bottom	cetaceans	state - state
corals and hard-bottom	climate regulation	state - ecosystem service
corals and hard-bottom	coastal protection	state - ecosystem service
corals and hard-bottom	education	state - ecosystem service
corals and hard-bottom	existence	state - ecosystem service
corals and hard-bottom	fish, shellfish, limu	state - ecosystem service
corals and hard-bottom	habitat	state - ecosystem service
corals and hard-bottom	Hawaiian cultural value	state - ecosystem service
corals and hard-bottom	heritage value	state - ecosystem service
corals and hard-bottom	inspiration value	state - ecosystem service
corals and hard-bottom	medicinal resources	state - ecosystem service
corals and hard-bottom	non extractive recreation	state - ecosystem service
corals and hard-bottom	nutrient cycling	state - ecosystem service
corals and hard-bottom	pelagic fishes	state - state
corals and hard-bottom	reef fishes	state - state
corals and hard-bottom	scientific research	state - ecosystem service
corals and hard-bottom	sense of place	state - ecosystem service
corals and hard-bottom	shells	state - ecosystem service
corals and hard-bottom	social interaction	state - ecosystem service
corals and hard-bottom	spiritual value	state - ecosystem service
corals and hard-bottom	transport infrastructure	state - ecosystem service

corals and hard-bottom	turtles	state - state
corals and hard-bottom	water body	state - state
corals and hard-bottom	water purification	state - ecosystem service
deforestation	algal overgrowth	driver - pressure
deforestation	coral disease	driver - pressure
deforestation	currents	driver - pressure
deforestation	extreme events	driver - pressure
deforestation	flooding	driver - pressure
deforestation	freshwater input	driver - pressure
deforestation	habitat destruction	driver - pressure
deforestation	human disturbance to animals	driver - pressure
deforestation	non-native invasive species	driver - pressure
deforestation	nutrient input	driver - pressure
deforestation	ocean pH	driver - pressure
deforestation	ocean temperature	driver - pressure
deforestation	other contaminants (sunscreen)	driver - pressure
deforestation	pesticides	driver - pressure
deforestation	sea level rise	driver - pressure
deforestation	sediments	driver - pressure
deforestation	wave forcing	driver - pressure
deforestation	wind	driver - pressure
erosion	algal overgrowth	driver - pressure
erosion	coral disease	driver - pressure
erosion	currents	driver - pressure
erosion	extreme events	driver - pressure
erosion	flooding	driver - pressure
erosion	freshwater input	driver - pressure
erosion	habitat destruction	driver - pressure
erosion	human disturbance to animals	driver - pressure
erosion	hydrocarbons	driver - pressure
erosion	marine debris	driver - pressure
erosion	non-native invasive species	driver - pressure
erosion	nutrient input	driver - pressure
erosion	ocean pH	driver - pressure
erosion	ocean temperature	driver - pressure
erosion	other contaminants (sunscreen)	driver - pressure
erosion	pesticides	driver - pressure
erosion	sea level rise	driver - pressure
erosion	sediments	driver - pressure
erosion	wave forcing	driver - pressure
erosion	wind	driver - pressure

feral ungulates	algal overgrowth	driver - pressure
feral ungulates	coral disease	driver - pressure
feral ungulates	currents	driver - pressure
feral ungulates	extreme events	driver - pressure
feral ungulates	flooding	driver - pressure
feral ungulates	freshwater input	driver - pressure
feral ungulates	habitat destruction	driver - pressure
feral ungulates	nutrient input	driver - pressure
feral ungulates	ocean pH	driver - pressure
feral ungulates	ocean temperature	driver - pressure
feral ungulates	other contaminants (sunscreen)	driver - pressure
feral ungulates	pesticides	driver - pressure
feral ungulates	sea level rise	driver - pressure
feral ungulates	sediments	driver - pressure
feral ungulates	wave forcing	driver - pressure
freshwater use & management	algal overgrowth	driver - pressure
freshwater use & management	coral disease	driver - pressure
freshwater use & management	currents	driver - pressure
freshwater use & management	extraction of fish	driver - pressure
freshwater use & management	extreme events	driver - pressure
freshwater use & management	flooding	driver - pressure
freshwater use & management	freshwater input	driver - pressure
freshwater use & management	habitat destruction	driver - pressure
freshwater use & management	human disturbance to animals	driver - pressure
freshwater use & management	hydrocarbons	driver - pressure
freshwater use & management	marine debris	driver - pressure
freshwater use & management	nutrient input	driver - pressure
freshwater use & management	ocean pH	driver - pressure
freshwater use & management	ocean temperature	driver - pressure
freshwater use & management	other contaminants (sunscreen)	driver - pressure
freshwater use & management	pesticides	driver - pressure
freshwater use & management	sea level rise	driver - pressure
freshwater use & management	sediments	driver - pressure
freshwater use & management	wave forcing	driver - pressure
groundwater transport	algal overgrowth	driver - pressure
groundwater transport	coral disease	driver - pressure
groundwater transport	currents	driver - pressure
groundwater transport	extreme events	driver - pressure
groundwater transport	flooding	driver - pressure
groundwater transport	freshwater input	driver - pressure
groundwater transport	habitat destruction	driver - pressure

groundwater transport	non-native invasive species	driver - pressure
groundwater transport	nutrient input	driver - pressure
groundwater transport	ocean pH	driver - pressure
groundwater transport	ocean temperature	driver - pressure
groundwater transport	other contaminants (sunscreen)	driver - pressure
groundwater transport	pesticides	driver - pressure
groundwater transport	sea level rise	driver - pressure
groundwater transport	sediments	driver - pressure
groundwater transport	wave forcing	driver - pressure
groundwater transport	wind	driver - pressure
land development & urban sprawl	algal overgrowth	driver - pressure
land development & urban sprawl	coral disease	driver - pressure
land development & urban sprawl	currents	driver - pressure
land development & urban sprawl	extraction of fish	driver - pressure
land development & urban sprawl	extreme events	driver - pressure
land development & urban sprawl	flooding	driver - pressure
land development & urban sprawl	freshwater input	driver - pressure
land development & urban sprawl	habitat destruction	driver - pressure
land development & urban sprawl	human disturbance to animals	driver - pressure
land development & urban sprawl	hydrocarbons	driver - pressure
land development & urban sprawl	marine debris	driver - pressure
land development & urban sprawl	non-native invasive species	driver - pressure
land development & urban sprawl	nutrient input	driver - pressure
land development & urban sprawl	ocean pH	driver - pressure
land development & urban sprawl	ocean temperature	driver - pressure
land development & urban sprawl	other contaminants (sunscreen)	driver - pressure
land development & urban sprawl	pesticides	driver - pressure
land development & urban sprawl	sea level rise	driver - pressure
land development & urban sprawl	sediments	driver - pressure
land development & urban sprawl	wave forcing	driver - pressure
land development & urban sprawl	wind	driver - pressure
local climate	algal overgrowth	driver - pressure
local climate	coral disease	driver - pressure
local climate	currents	driver - pressure
local climate	extreme events	driver - pressure
local climate	flooding	driver - pressure
local climate	freshwater input	driver - pressure
local climate	habitat destruction	driver - pressure
local climate	marine debris	driver - pressure
local climate	non-native invasive species	driver - pressure
local climate	nutrient input	driver - pressure

local climate	ocean pH	driver - pressure
local climate	ocean temperature	driver - pressure
local climate	sea level rise	driver - pressure
local climate	sediments	driver - pressure
local climate	wave forcing	driver - pressure
local climate	wind	driver - pressure
non-commercial fishing	algal overgrowth	driver - pressure
non-commercial fishing	coral disease	driver - pressure
non-commercial fishing	extraction of fish	driver - pressure
non-commercial fishing	extreme events	driver - pressure
non-commercial fishing	habitat destruction	driver - pressure
non-commercial fishing	human disturbance to animals	driver - pressure
non-commercial fishing	marine debris	driver - pressure
non-commercial fishing	non-native invasive species	driver - pressure
non-commercial fishing	other contaminants (sunscreen)	driver - pressure
ocean dynamics	algal overgrowth	driver - pressure
ocean dynamics	coral disease	driver - pressure
ocean dynamics	currents	driver - pressure
ocean dynamics	extreme events	driver - pressure
ocean dynamics	flooding	driver - pressure
ocean dynamics	freshwater input	driver - pressure
ocean dynamics	habitat destruction	driver - pressure
ocean dynamics	hydrocarbons	driver - pressure
ocean dynamics	marine debris	driver - pressure
ocean dynamics	non-native invasive species	driver - pressure
ocean dynamics	nutrient input	driver - pressure
ocean dynamics	ocean pH	driver - pressure
ocean dynamics	ocean temperature	driver - pressure
ocean dynamics	other contaminants (sunscreen)	driver - pressure
ocean dynamics	pesticides	driver - pressure
ocean dynamics	sea level rise	driver - pressure
ocean dynamics	sediments	driver - pressure
ocean dynamics	wave forcing	driver - pressure
ocean dynamics	wind	driver - pressure
ocean tourism	habitat destruction	driver - pressure
ocean tourism	human disturbance to animals	driver - pressure
ocean tourism	hydrocarbons	driver - pressure
ocean tourism	other contaminants (sunscreen)	driver - pressure
recreational land use	algal overgrowth	driver - pressure
recreational land use	extraction of fish	driver - pressure
recreational land use	hydrocarbons	driver - pressure

recreational ocean use	habitat destruction	driver - pressure
recreational ocean use	other contaminants (sunscreen)	driver - pressure
resorts & golf courses	algal overgrowth	driver - pressure
resorts & golf courses	coral disease	driver - pressure
resorts & golf courses	currents	driver - pressure
resorts & golf courses	extraction of fish	driver - pressure
resorts & golf courses	extreme events	driver - pressure
resorts & golf courses	flooding	driver - pressure
resorts & golf courses	freshwater input	driver - pressure
resorts & golf courses	habitat destruction	driver - pressure
resorts & golf courses	human disturbance to animals	driver - pressure
resorts & golf courses	hydrocarbons	driver - pressure
resorts & golf courses	marine debris	driver - pressure
resorts & golf courses	non-native invasive species	driver - pressure
resorts & golf courses	nutrient input	driver - pressure
resorts & golf courses	ocean pH	driver - pressure
resorts & golf courses	ocean temperature	driver - pressure
resorts & golf courses	other contaminants (sunscreen)	driver - pressure
resorts & golf courses	pesticides	driver - pressure
resorts & golf courses	sea level rise	driver - pressure
resorts & golf courses	sediments	driver - pressure
resorts & golf courses	wave forcing	driver - pressure
wastewater disposal systems	algal overgrowth	driver - pressure
wastewater disposal systems	coral disease	driver - pressure
wastewater disposal systems	currents	driver - pressure
wastewater disposal systems	extreme events	driver - pressure
wastewater disposal systems	flooding	driver - pressure
wastewater disposal systems	freshwater input	driver - pressure
wastewater disposal systems	hydrocarbons	driver - pressure
wastewater disposal systems	non-native invasive species	driver - pressure
wastewater disposal systems	nutrient input	driver - pressure
wastewater disposal systems	ocean pH	driver - pressure
wastewater disposal systems	ocean temperature	driver - pressure
wastewater disposal systems	other contaminants (sunscreen)	driver - pressure
wastewater disposal systems	pesticides	driver - pressure
wastewater disposal systems	sea level rise	driver - pressure
wastewater disposal systems	sediments	driver - pressure
wastewater disposal systems	wave forcing	driver - pressure
wastewater disposal systems	wind	driver - pressure

Pealgic Fishes

Specific Type	Type
recreational ocean use	**driver**
boating / personal watercrafts	**driver**
aquarium fish collection	driver
agriculture	driver
erosion	driver
ocean dynamics	**driver**
commercial fishing	**driver**
deforestation	driver

land development & urban sprawl	driver
local climate	**driver**
non-commercial fishing	**driver**
ocean tourism	**driver**
shipping	*driver*
aesthetic environment	**impacted ecosystem service**
aquarium fish	impacted ecosystem service
atmospheric regulation	impacted ecosystem service
biodiversity	**impacted ecosystem service**
biological Interactions	**impacted ecosystem service**
biotechnology resources	**impacted ecosystem service**
climate regulation	impacted ecosystem service
education	**impacted ecosystem service**
existence	**impacted ecosystem service**
fish, shellfish, limu	**impacted ecosystem service**
habitat	**impacted ecosystem service**
Hawaiian cultural value	**impacted ecosystem service**
heritage value	**impacted ecosystem service**
inspirational value	impacted ecosystem service
medicinal resources	**impacted ecosystem service**
non-extractive recreation	**impacted ecosystem service**
nutrient cycling	**impacted ecosystem service**
scientific research	**impacted ecosystem service**
sense of place	impacted ecosystem service
shells	impacted ecosystem service
social Interaction	impacted ecosystem service
spiritual value	impacted ecosystem service
algal overgrowth	**pressure**
coral disease	**pressure**
extraction of fish	**pressure**
extreme events	**pressure**
fish parasites / disease	pressure
freshwater input	**pressure**
habitat destruction	**pressure**
human disturbance to animals	**pressure**
hydrocarbons	**pressure**
marine debris	**pressure**
non-native invasive species	**pressure**
nutrient input	**pressure**
ocean pH	**pressure**
ocean temperature	**pressure**
other contaminants (sunscreen)	**pressure**
pathogens	**pressure**
pharmaceuticals	**pressure**
precipitation	**pressure**
sediments	**pressure**
wind	**pressure**
pesticides	*pressure*
reef fishes	ecosystem state
water body	ecosystem state
Turtles	ecosystem state
Cetaceans	ecosystem state
corals and hard-bottom	ecosystem state

bold = identified at HCC and in survey 40
regular = identified only in survey 18
italics = identified only at HCC 2

Pelagic Fishes

From	To	Interaction Description
beach use	ocean pH	driver - pressure
recreational ocean use	human disturbance to animals	driver - pressure
recreational ocean use	hydrocarbons	driver - pressure
boating / personal watercrafts	human disturbance to animals	driver - pressure
boating / personal watercrafts	extraction of fish	driver - pressure
boating / personal watercrafts	hydrocarbons	driver - pressure
aquarium fish collection	extraction of fish	driver - pressure
agriculture	habitat destruction	driver - pressure
agriculture	nutrient input	driver - pressure
agriculture	sediments	driver - pressure
agriculture	other contaminants (sunscreen)	driver - pressure
agriculture	hydrocarbons	driver - pressure
agriculture	pesticides	driver - pressure
agriculture	pharmaceuticals	driver - pressure
agriculture	pathogens	driver - pressure
agriculture	ocean temperature	driver - pressure
agriculture	ocean pH	driver - pressure
erosion	habitat destruction	driver - pressure
erosion	nutrient input	driver - pressure
erosion	sediments	driver - pressure
erosion	other contaminants (sunscreen)	driver - pressure
erosion	pesticides	driver - pressure
ocean dynamics	habitat destruction	driver - pressure
ocean dynamics	marine debris	driver - pressure
ocean dynamics	nutrient input	driver - pressure
ocean dynamics	fish parasites / disease	driver - pressure
ocean dynamics	ocean temperature	driver - pressure
ocean dynamics	ocean pH	driver - pressure
ocean dynamics	extreme events	driver - pressure
ocean dynamics	freshwater input	driver - pressure
commercial fishing	habitat destruction	driver - pressure
commercial fishing	marine debris	driver - pressure
commercial fishing	human disturbance to animals	driver - pressure
commercial fishing	extraction of fish	driver - pressure
commercial fishing	hydrocarbons	driver - pressure
commercial fishing	non-native invasive species	driver - pressure

commercial fishing	algal overgrowth	driver - pressure
commercial fishing	coral disease	driver - pressure
commercial fishing	fish parasites / disease	driver - pressure
commercial fishing	ocean pH	driver - pressure
deforestation	habitat destruction	driver - pressure
deforestation	nutrient input	driver - pressure
deforestation	sediments	driver - pressure
deforestation	other contaminants (sunscreen)	driver - pressure
deforestation	ocean temperature	driver - pressure
deforestation	ocean pH	driver - pressure
land development & urban sprawl	habitat destruction	driver - pressure
land development & urban sprawl	marine debris	driver - pressure
land development & urban sprawl	nutrient input	driver - pressure
land development & urban sprawl	sediments	driver - pressure
land development & urban sprawl	other contaminants (sunscreen)	driver - pressure
land development & urban sprawl	hydrocarbons	driver - pressure
land development & urban sprawl	pesticides	driver - pressure
land development & urban sprawl	pharmaceuticals	driver - pressure
land development & urban sprawl	pathogens	driver - pressure
land development & urban sprawl	fish parasites / disease	driver - pressure
land development & urban sprawl	ocean temperature	driver - pressure
land development & urban sprawl	ocean pH	driver - pressure
local climate	habitat destruction	driver - pressure
local climate	ocean temperature	driver - pressure
local climate	wind	driver - pressure
local climate	precipitation	driver - pressure
non-commercial fishing	human disturbance to animals	driver - pressure
non-commercial fishing	extraction of fish	driver - pressure
ocean tourism	human disturbance to animals	driver - pressure
ocean tourism	hydrocarbons	driver - pressure
ocean tourism	ocean pH	driver - pressure
pelagic fishes	reef fishes	state - state
pelagic fishes	corals and hard-bottom	state - state
pelagic fishes	water body	state - state
pelagic fishes	turtles	state - state
pelagic fishes	cetaceans	state - state
pelagic fishes	fish, shellfish, limu	state - ecosystem service
pelagic fishes	aquarium fish	state - ecosystem service
pelagic fishes	shells	state - ecosystem service
pelagic fishes	medicinal resources	state - ecosystem service
pelagic fishes	biotechnology resources	state - ecosystem service
pelagic fishes	biodiversity	state - ecosystem service
pelagic fishes	habitat	state - ecosystem service

pelagic fishes	nutrient cycling	state - ecosystem service
pelagic fishes	biological interactions	state - ecosystem service
pelagic fishes	climate regulation	state - ecosystem service
pelagic fishes	atmospheric regulation	state - ecosystem service
pelagic fishes	aesthetic environment	state - ecosystem service
pelagic fishes	existence	state - ecosystem service
pelagic fishes	non extractive recreation	state - ecosystem service
pelagic fishes	scientific research	state - ecosystem service
pelagic fishes	education	state - ecosystem service
pelagic fishes	Hawaiian cultural value	state - ecosystem service
pelagic fishes	heritage value	state - ecosystem service
pelagic fishes	spiritual value	state - ecosystem service
pelagic fishes	social interaction	state - ecosystem service
pelagic fishes	inspiration value	state - ecosystem service
pelagic fishes	sense of place	state - ecosystem service

Reef Fishes

Specific Type	Type
beach use	**driver**
recreational ocean use	**driver**
boating / personal watercrafts	**driver**
freshwater use & management	**driver**
aquarium fish collection	**driver**
agriculture	**driver**
groundwater transport	**driver**
erosion	**driver**
ocean dynamics	**driver**
global climate (CHW)	driver
disease (CHW)	driver
toxicity (CHW)	driver
animal production	**driver**
commercial fishing	**driver**
deforestation	**driver**
feral ungulates	**driver**
land development & urban sprawl	**driver**
local climate	driver
non-commercial fishing	**driver**
ocean tourism	**driver**
recreational land use	**driver**
resorts & golf courses	**driver**
wastewater disposal systems	**driver**
corals and hard-bottom	ecosystem state
pelagic fishes	ecosystem state
water body	ecosystem state
turtles	ecosystem state
cetaceans	ecosystem state
beaches	ecosystem state
anchialine ponds	ecosystem state
aesthetic environment	impacted ecosystem service
aquarium fish	impacted ecosystem service
atmospheric regulation	**impacted ecosystem service**
biodiversity	impacted ecosystem service
biological Interactions	impacted ecosystem service

biotechnology resources	impacted ecosystem service
climate regulation	**impacted ecosystem service**
coastal protection	impacted ecosystem service
education	impacted ecosystem service
existence	**impacted ecosystem service**
fish, shellfish, limu	impacted ecosystem service
habitat	impacted ecosystem service
Hawaiian cultural value	impacted ecosystem service
heritage value	impacted ecosystem service
inspirational value	**impacted ecosystem service**
medicinal resources	impacted ecosystem service
non-extractive recreation	impacted ecosystem service
nutrient cycling	impacted ecosystem service
scientific research	impacted ecosystem service
sense of place	**impacted ecosystem service**
shells	**impacted ecosystem service**
social Interaction	impacted ecosystem service
spiritual value	impacted ecosystem service
transport infrastructure	**impacted ecosystem service**
water purification	**impacted ecosystem service**
habitat destruction	**pressure**
algal overgrowth	**pressure**
coral disease	**pressure**
extraction of fish	**pressure**
human disturbance to animals	**pressure**
non-native invasive species	**pressure**
marine debris	**pressure**
nutrient input	**pressure**
ocean temperature	**pressure**
sediments	**pressure**
fish mortality	pressure
toxicity	pressure
other contaminants (sunscreen)	pressure
hydrocarbons	pressure
pesticides	pressure
pathogens	**pressure**
discarded gear	pressure
fish parasites / disease	pressure
pharmaceuticals	pressure
ocean pH	**pressure**
extreme events	**pressure**
freshwater input	**pressure**
flooding	**pressure**
other comment: Huge pressure by influx of Marshal Island and Micronesian people. Big problem (DD)	extraction of fish

bold = identified at HCC and in survey	42
regular = identified only in survey	36

Reef Fishes

From	To	Interaction Description
beach use	habitat destruction	driver - pressure

beach use	marine debris	driver - pressure
beach use	nutrient input	driver - pressure
beach use	sediments	driver - pressure
beach use	other contaminants (sunscreen)	driver - pressure
beach use	hydrocarbons	driver - pressure
beach use	pharmaceuticals	driver - pressure
beach use	pathogens	driver - pressure
beach use	human disturbance to animals	driver - pressure
beach use	algal overgrowth	driver - pressure
beach use	coral disease	driver - pressure
beach use	freshwater input	driver - pressure
recreational ocean use	habitat destruction	driver - pressure
recreational ocean use	marine debris	driver - pressure
recreational ocean use	other contaminants (sunscreen)	driver - pressure
recreational ocean use	hydrocarbons	driver - pressure
recreational ocean use	pathogens	driver - pressure
recreational ocean use	human disturbance to animals	driver - pressure
recreational ocean use	algal overgrowth	driver - pressure
recreational ocean use	coral disease	driver - pressure
boating / personal watercrafts	human disturbance to animals	driver - pressure
boating / personal watercrafts	nutrient input	driver - pressure
boating / personal watercrafts	other contaminants (sunscreen)	driver - pressure
boating / personal watercrafts	hydrocarbons	driver - pressure
boating / personal watercrafts	pharmaceuticals	driver - pressure
boating / personal watercrafts	pathogens	driver - pressure
boating / personal watercrafts	habitat destruction	driver - pressure
boating / personal watercrafts	algal overgrowth	driver - pressure
boating / personal watercrafts	coral disease	driver - pressure
freshwater use & management	habitat destruction	driver - pressure
freshwater use & management	marine debris	driver - pressure
freshwater use & management	human disturbance to animals	driver - pressure
freshwater use & management	nutrient input	driver - pressure
freshwater use & management	sediments	driver - pressure
freshwater use & management	other contaminants (sunscreen)	driver - pressure
freshwater use & management	hydrocarbons	driver - pressure
freshwater use & management	pesticides	driver - pressure
freshwater use & management	pharmaceuticals	driver - pressure
freshwater use & management	pathogens	driver - pressure
freshwater use & management	non-native invasive species	driver - pressure
freshwater use & management	algal overgrowth	driver - pressure
freshwater use & management	coral disease	driver - pressure

freshwater use & management	ocean temperature	driver - pressure
freshwater use & management	ocean pH	driver - pressure
freshwater use & management	extreme events	driver - pressure
freshwater use & management	freshwater input	driver - pressure
freshwater use & management	flooding	driver - pressure
aquarium fish collection	habitat destruction	driver - pressure
aquarium fish collection	marine debris	driver - pressure
aquarium fish collection	human disturbance to animals	driver - pressure
aquarium fish collection	nutrient input	driver - pressure
aquarium fish collection	other contaminants (sunscreen)	driver - pressure
aquarium fish collection	hydrocarbons	driver - pressure
aquarium fish collection	pharmaceuticals	driver - pressure
aquarium fish collection	pathogens	driver - pressure
aquarium fish collection	extraction of fish	driver - pressure
aquarium fish collection	non-native invasive species	driver - pressure
aquarium fish collection	algal overgrowth	driver - pressure
aquarium fish collection	coral disease	driver - pressure
agriculture	habitat destruction	driver - pressure
agriculture	marine debris	driver - pressure
agriculture	human disturbance to animals	driver - pressure
agriculture	nutrient input	driver - pressure
agriculture	sediments	driver - pressure
agriculture	other contaminants (sunscreen)	driver - pressure
agriculture	hydrocarbons	driver - pressure
agriculture	pesticides	driver - pressure
agriculture	pharmaceuticals	driver - pressure
agriculture	pathogens	driver - pressure
agriculture	non-native invasive species	driver - pressure
agriculture	algal overgrowth	driver - pressure
agriculture	coral disease	driver - pressure
agriculture	fish parasites / disease	driver - pressure
agriculture	ocean temperature	driver - pressure
agriculture	ocean pH	driver - pressure
agriculture	extreme events	driver - pressure
agriculture	freshwater input	driver - pressure
agriculture	flooding	driver - pressure
groundwater transport	habitat destruction	driver - pressure
groundwater transport	human disturbance to animals	driver - pressure
groundwater transport	fish mortality	driver - pressure
groundwater transport	nutrient input	driver - pressure
groundwater transport	sediments	driver - pressure

groundwater transport	pesticides	driver - pressure
groundwater transport	pharmaceuticals	driver - pressure
groundwater transport	pathogens	driver - pressure
groundwater transport	algal overgrowth	driver - pressure
groundwater transport	coral disease	driver - pressure
groundwater transport	fish parasites / disease	driver - pressure
groundwater transport	ocean temperature	driver - pressure
groundwater transport	ocean pH	driver - pressure
groundwater transport	extreme events	driver - pressure
groundwater transport	freshwater input	driver - pressure
groundwater transport	flooding	driver - pressure
erosion	habitat destruction	driver - pressure
erosion	nutrient input	driver - pressure
erosion	sediments	driver - pressure
erosion	hydrocarbons	driver - pressure
erosion	pathogens	driver - pressure
erosion	non-native invasive species	driver - pressure
erosion	algal overgrowth	driver - pressure
erosion	coral disease	driver - pressure
erosion	ocean pH	driver - pressure
erosion	extreme events	driver - pressure
erosion	freshwater input	driver - pressure
erosion	flooding	driver - pressure
ocean dynamics	habitat destruction	driver - pressure
ocean dynamics	nutrient input	driver - pressure
ocean dynamics	sediments	driver - pressure
ocean dynamics	other contaminants (sunscreen)	driver - pressure
ocean dynamics	hydrocarbons	driver - pressure
ocean dynamics	pesticides	driver - pressure
ocean dynamics	pharmaceuticals	driver - pressure
ocean dynamics	pathogens	driver - pressure
ocean dynamics	non-native invasive species	driver - pressure
ocean dynamics	algal overgrowth	driver - pressure
ocean dynamics	coral disease	driver - pressure
ocean dynamics	fish parasites / disease	driver - pressure
ocean dynamics	ocean temperature	driver - pressure
ocean dynamics	ocean pH	driver - pressure
ocean dynamics	extreme events	driver - pressure
ocean dynamics	freshwater input	driver - pressure
ocean dynamics	flooding	driver - pressure
global climate (CHW)	extraction of fish	driver - pressure

global climate (CHW)	hydrocarbons	driver - pressure
global climate (CHW)	ocean temperature	driver - pressure
global climate (CHW)	ocean pH	driver - pressure
global climate (CHW)	freshwater input	driver - pressure
global climate (CHW)	flooding	driver - pressure
disease (CHW)	extraction of fish	driver - pressure
toxicity (CHW)	non-native invasive species	driver - pressure
animal production	habitat destruction	driver - pressure
animal production	fish mortality	driver - pressure
animal production	nutrient input	driver - pressure
animal production	sediments	driver - pressure
animal production	other contaminants (sunscreen)	driver - pressure
animal production	hydrocarbons	driver - pressure
animal production	pesticides	driver - pressure
animal production	pharmaceuticals	driver - pressure
animal production	pathogens	driver - pressure
animal production	non-native invasive species	driver - pressure
animal production	algal overgrowth	driver - pressure
animal production	coral disease	driver - pressure
animal production	ocean pH	driver - pressure
animal production	extreme events	driver - pressure
animal production	freshwater input	driver - pressure
animal production	flooding	driver - pressure
commercial fishing	habitat destruction	driver - pressure
commercial fishing	marine debris	driver - pressure
commercial fishing	human disturbance to animals	driver - pressure
commercial fishing	nutrient input	driver - pressure
commercial fishing	other contaminants (sunscreen)	driver - pressure
commercial fishing	hydrocarbons	driver - pressure
commercial fishing	pharmaceuticals	driver - pressure
commercial fishing	pathogens	driver - pressure
commercial fishing	discarded gear	driver - pressure
commercial fishing	extraction of fish	driver - pressure
commercial fishing	non-native invasive species	driver - pressure
commercial fishing	algal overgrowth	driver - pressure
commercial fishing	coral disease	driver - pressure
deforestation	habitat destruction	driver - pressure
deforestation	nutrient input	driver - pressure
deforestation	sediments	driver - pressure
deforestation	hydrocarbons	driver - pressure
deforestation	pathogens	driver - pressure

deforestation	non-native invasive species	driver - pressure
deforestation	algal overgrowth	driver - pressure
deforestation	coral disease	driver - pressure
deforestation	ocean pH	driver - pressure
deforestation	extreme events	driver - pressure
deforestation	freshwater input	driver - pressure
deforestation	flooding	driver - pressure
feral ungulates	habitat destruction	driver - pressure
feral ungulates	nutrient input	driver - pressure
feral ungulates	sediments	driver - pressure
feral ungulates	hydrocarbons	driver - pressure
feral ungulates	pathogens	driver - pressure
feral ungulates	non-native invasive species	driver - pressure
feral ungulates	algal overgrowth	driver - pressure
feral ungulates	coral disease	driver - pressure
feral ungulates	ocean pH	driver - pressure
feral ungulates	extreme events	driver - pressure
feral ungulates	freshwater input	driver - pressure
feral ungulates	flooding	driver - pressure
land development & urban sprawl	habitat destruction	driver - pressure
land development & urban sprawl	marine debris	driver - pressure
land development & urban sprawl	human disturbance to animals	driver - pressure
land development & urban sprawl	nutrient input	driver - pressure
land development & urban sprawl	sediments	driver - pressure
land development & urban sprawl	other contaminants (sunscreen)	driver - pressure
land development & urban sprawl	hydrocarbons	driver - pressure
land development & urban sprawl	pesticides	driver - pressure
land development & urban sprawl	pharmaceuticals	driver - pressure
land development & urban sprawl	pathogens	driver - pressure
land development & urban sprawl	non-native invasive species	driver - pressure
land development & urban sprawl	algal overgrowth	driver - pressure
land development & urban sprawl	coral disease	driver - pressure
land development & urban sprawl	fish parasites / disease	driver - pressure
land development & urban sprawl	ocean temperature	driver - pressure
land development & urban sprawl	ocean pH	driver - pressure
land development & urban sprawl	extreme events	driver - pressure
land development & urban sprawl	freshwater input	driver - pressure
land development & urban sprawl	flooding	driver - pressure
local climate	habitat destruction	driver - pressure
local climate	nutrient input	driver - pressure
local climate	sediments	driver - pressure

local climate	hydrocarbons	driver - pressure
local climate	pesticides	driver - pressure
local climate	pharmaceuticals	driver - pressure
local climate	pathogens	driver - pressure
local climate	non-native invasive species	driver - pressure
local climate	algal overgrowth	driver - pressure
local climate	coral disease	driver - pressure
local climate	fish parasites / disease	driver - pressure
local climate	ocean temperature	driver - pressure
local climate	ocean pH	driver - pressure
local climate	extreme events	driver - pressure
local climate	freshwater input	driver - pressure
local climate	flooding	driver - pressure
non-commercial fishing	habitat destruction	driver - pressure
non-commercial fishing	marine debris	driver - pressure
non-commercial fishing	human disturbance to animals	driver - pressure
non-commercial fishing	nutrient input	driver - pressure
non-commercial fishing	other contaminants (sunscreen)	driver - pressure
non-commercial fishing	hydrocarbons	driver - pressure
non-commercial fishing	pharmaceuticals	driver - pressure
non-commercial fishing	pathogens	driver - pressure
non-commercial fishing	discarded gear	driver - pressure
non-commercial fishing	extraction of fish	driver - pressure
non-commercial fishing	non-native invasive species	driver - pressure
non-commercial fishing	algal overgrowth	driver - pressure
non-commercial fishing	coral disease	driver - pressure
ocean tourism	habitat destruction	driver - pressure
ocean tourism	marine debris	driver - pressure
ocean tourism	nutrient input	driver - pressure
ocean tourism	other contaminants (sunscreen)	driver - pressure
ocean tourism	hydrocarbons	driver - pressure
ocean tourism	pharmaceuticals	driver - pressure
ocean tourism	pathogens	driver - pressure
ocean tourism	human disturbance to animals	driver - pressure
ocean tourism	algal overgrowth	driver - pressure
ocean tourism	coral disease	driver - pressure
recreational land use	habitat destruction	driver - pressure
recreational land use	nutrient input	driver - pressure
recreational land use	sediments	driver - pressure
recreational land use	other contaminants (sunscreen)	driver - pressure
recreational land use	hydrocarbons	driver - pressure

recreational land use	pesticides	driver - pressure
recreational land use	pathogens	driver - pressure
recreational land use	marine debris	driver - pressure
recreational land use	algal overgrowth	driver - pressure
recreational land use	coral disease	driver - pressure
recreational land use	flooding	driver - pressure
resorts & golf courses	habitat destruction	driver - pressure
resorts & golf courses	marine debris	driver - pressure
resorts & golf courses	human disturbance to animals	driver - pressure
resorts & golf courses	nutrient input	driver - pressure
resorts & golf courses	sediments	driver - pressure
resorts & golf courses	other contaminants (sunscreen)	driver - pressure
resorts & golf courses	hydrocarbons	driver - pressure
resorts & golf courses	pesticides	driver - pressure
resorts & golf courses	pharmaceuticals	driver - pressure
resorts & golf courses	pathogens	driver - pressure
resorts & golf courses	non-native invasive species	driver - pressure
resorts & golf courses	algal overgrowth	driver - pressure
resorts & golf courses	coral disease	driver - pressure
resorts & golf courses	fish parasites / disease	driver - pressure
resorts & golf courses	ocean pH	driver - pressure
resorts & golf courses	extreme events	driver - pressure
resorts & golf courses	freshwater input	driver - pressure
resorts & golf courses	flooding	driver - pressure
wastewater disposal systems	habitat destruction	driver - pressure
wastewater disposal systems	marine debris	driver - pressure
wastewater disposal systems	human disturbance to animals	driver - pressure
wastewater disposal systems	nutrient input	driver - pressure
wastewater disposal systems	sediments	driver - pressure
wastewater disposal systems	other contaminants (sunscreen)	driver - pressure
wastewater disposal systems	hydrocarbons	driver - pressure
wastewater disposal systems	pesticides	driver - pressure
wastewater disposal systems	pharmaceuticals	driver - pressure
wastewater disposal systems	pathogens	driver - pressure
wastewater disposal systems	non-native invasive species	driver - pressure
wastewater disposal systems	algal overgrowth	driver - pressure
wastewater disposal systems	coral disease	driver - pressure
wastewater disposal systems	fish parasites / disease	driver - pressure
wastewater disposal systems	ocean temperature	driver - pressure
wastewater disposal systems	ocean pH	driver - pressure
wastewater disposal systems	extreme events	driver - pressure

wastewater disposal systems	freshwater input	driver - pressure
wastewater disposal systems	flooding	driver - pressure
habitat destruction	reef fishes	pressure - state
algal overgrowth	reef fishes	pressure - state
coral disease	reef fishes	pressure - state
extraction of fish	reef fishes	pressure - state
human disturbance to wild animals	reef fishes	pressure - state
non-native invasive species	reef fishes	pressure - state
marine debris	reef fishes	pressure - state
nutrient input	reef fishes	pressure - state
ocean temperature	reef fishes	pressure - state
sediments	reef fishes	pressure - state
fish mortality	reef fishes	pressure - state
toxicity	reef fishes	pressure - state
other contaminants (sunscreen)	reef fishes	pressure - state
hydrocarbons	reef fishes	pressure - state
pesticides	reef fishes	pressure - state
pathogens	reef fishes	pressure - state
discarded gear	reef fishes	pressure - state
fish parasites / disease	reef fishes	pressure - state
ocean pH	reef fishes	pressure - state
extreme events	reef fishes	pressure - state
freshwater input	reef fishes	pressure - state
flooding	reef fishes	pressure - state
reef fishes	corals and hard-bottom	state - state
reef fishes	pelagic fishes	state - state
reef fishes	water body	state - state
reef fishes	turtles	state - state
reef fishes	cetaceans	state - state
reef fishes	beaches	state - state
reef fishes	anchialine ponds	state - state
reef fishes	fish, shellfish, limu	state - ecosystem service
reef fishes	aquarium fish	state - ecosystem service
reef fishes	shells	state - ecosystem service
reef fishes	medicinal resources	state - ecosystem service
reef fishes	biotechnology resources	state - ecosystem service
reef fishes	transport infrastructure	state - ecosystem service
reef fishes	biodiversity	state - ecosystem service
reef fishes	habitat	state - ecosystem service
reef fishes	nutrient cycling	state - ecosystem service
reef fishes	biological interactions	state - ecosystem service
reef fishes	climate regulation	state - ecosystem service
reef fishes	atmospheric regulation	state - ecosystem service
reef fishes	water purification	state - ecosystem service

reef fishes	coastal protection	state - ecosystem service
reef fishes	aesthetic environment	state - ecosystem service
reef fishes	existence	state - ecosystem service
reef fishes	non-extractive recreation	state - ecosystem service
reef fishes	scientific research	state - ecosystem service
reef fishes	education	state - ecosystem service
reef fishes	Hawaiian cultural value	state - ecosystem service
reef fishes	heritage value	state - ecosystem service
reef fishes	spiritual value	state - ecosystem service
reef fishes	social interaction	state - ecosystem service
reef fishes	inspirational value	state - ecosystem service
reef fishes	sense of place	state - ecosystem service

The Water Body

Specific Type	Type
beach use	driver
recreational ocean use	driver
recreational land use	driver
boating / personal watercrafts	driver
aquarium fish collection	driver
resorts & golf courses	**driver**
freshwater use & management	**driver**
wastewater disposal systems	**driver**
agriculture	**driver**
animal production	**driver**
feral ungulates	**driver**
groundwater transport	**driver**
erosion	**driver**
ocean dynamics	**driver**
commercial fishing	driver
deforestation	**driver**
land development & urban sprawl	**driver**
local climate	**driver**
non-commercial fishing	driver
ocean tourism	driver
aquaculture	*driver*
changes in access	*driver*
non-native invasive species	*driver*
aesthetic environment	**impacted ecosystem service**
aquarium fish	**impacted ecosystem service**
atmospheric regulation	**impacted ecosystem service**
biodiversity	**impacted ecosystem service**
biological Interactions	**impacted ecosystem service**
biotechnology resources	**impacted ecosystem service**
climate regulation	**impacted ecosystem service**
education	**impacted ecosystem service**
existence	**impacted ecosystem service**
fish, shellfish, limu	**impacted ecosystem service**
habitat	**impacted ecosystem service**
Hawaiian cultural value	**impacted ecosystem service**
heritage value	**impacted ecosystem service**
inspirational value	impacted ecosystem service
medicinal resources	**impacted ecosystem service**

non-extractive recreation	**impacted ecosystem service**
nutrient cycling	**impacted ecosystem service**
scientific research	**impacted ecosystem service**
sense of place	impacted ecosystem service
shells	**impacted ecosystem service**
social Interaction	**impacted ecosystem service**
spiritual value	**impacted ecosystem service**
algal overgrowth	**pressure**
coral disease	**pressure**
extraction of fish	**pressure**
freshwater input	**pressure**
habitat destruction	**pressure**
human disturbance to animals	**pressure**
hydrocarbons	**pressure**
marine debris	**pressure**
non-native invasive species	**pressure**
nutrient input	**pressure**
ocean pH	**pressure**
other contaminants	**pressure**
pathogens	**pressure**
pesticides	**pressure**
pharmaceuticals	**pressure**
precipitation	**pressure**
sea level rise	**pressure**
sediments	**pressure**
lava	*pressure*
ocean temperature	*pressure*
extreme events	*pressure*
pelagic fishes	ecosystem state
turtles	ecosystem state
cetaceans	ecosystem state
reef fishes	ecosystem state
beaches	ecosystem state
anchialine ponds	ecosystem state
corals and hard-bottom	ecosystem state

bold = identified at HCC and in survey	50
regular = identified only in survey	17
italics = identified only at HCC	6

The Water Body

From	To	Interaction Description
agriculture	algal overgrowth	driver - pressure
agriculture	coral disease	driver - pressure
agriculture	habitat destruction	driver - pressure
agriculture	hydrocarbons	driver - pressure
agriculture	nutrient input	driver - pressure
agriculture	other contaminants	driver - pressure
agriculture	pathogens	driver - pressure
agriculture	pesticides	driver - pressure

agriculture	precipitation	driver - pressure
agriculture	sediments	driver - pressure
animal production	algal overgrowth	driver - pressure
animal production	nutrient input	driver - pressure
animal production	pathogens	driver - pressure
animal production	sediments	driver - pressure
aquarium fish collection	extraction of fish	driver - pressure
aquarium fish collection	habitat destruction	driver - pressure
aquarium fish collection	human disturbance to animals	driver - pressure
aquarium fish collection	marine debris	driver - pressure
beach use	habitat destruction	driver - pressure
beach use	human disturbance to animals	driver - pressure
beach use	marine debris	driver - pressure
beach use	other contaminants	driver - pressure
boating / personal watercrafts	habitat destruction	driver - pressure
boating / personal watercrafts	human disturbance to animals	driver - pressure
boating / personal watercrafts	hydrocarbons	driver - pressure
boating / personal watercrafts	marine debris	driver - pressure
boating / personal watercrafts	other contaminants	driver - pressure
commercial fishing	extraction of fish	driver - pressure
commercial fishing	habitat destruction	driver - pressure
commercial fishing	human disturbance to animals	driver - pressure
commercial fishing	marine debris	driver - pressure
deforestation	algal overgrowth	driver - pressure
deforestation	freshwater input	driver - pressure
deforestation	habitat destruction	driver - pressure
deforestation	nutrient input	driver - pressure
deforestation	ocean pH	driver - pressure
deforestation	ocean temperature	driver - pressure
deforestation	other contaminants	driver - pressure
deforestation	pesticides	driver - pressure
deforestation	precipitation	driver - pressure
deforestation	sea level rise	driver - pressure
deforestation	sediments	driver - pressure
erosion	algal overgrowth	driver - pressure
erosion	habitat destruction	driver - pressure
erosion	hydrocarbons	driver - pressure
erosion	nutrient input	driver - pressure
erosion	other contaminants	driver - pressure
erosion	pesticides	driver - pressure
erosion	precipitation	driver - pressure

erosion	sediments	driver - pressure
feral ungulates	algal overgrowth	driver - pressure
feral ungulates	nutrient input	driver - pressure
feral ungulates	pathogens	driver - pressure
feral ungulates	sediments	driver - pressure
freshwater use and management	algal overgrowth	driver - pressure
freshwater use and management	coral disease	driver - pressure
freshwater use and management	freshwater input	driver - pressure
freshwater use and management	habitat destruction	driver - pressure
freshwater use and management	human disturbance to animals	driver - pressure
freshwater use and management	nutrient input	driver - pressure
freshwater use and management	ocean pH	driver - pressure
freshwater use and management	precipitation	driver - pressure
freshwater use and management	sediments	driver - pressure
groundwater transport	coral disease	driver - pressure
groundwater transport	freshwater input	driver - pressure
groundwater transport	habitat destruction	driver - pressure
groundwater transport	human disturbance to animals	driver - pressure
groundwater transport	nutrient input	driver - pressure
groundwater transport	other contaminants	driver - pressure
groundwater transport	pathogens	driver - pressure
groundwater transport	pesticides	driver - pressure
groundwater transport	pharmaceuticals	driver - pressure
groundwater transport	precipitation	driver - pressure
groundwater transport	sediments	driver - pressure
land development & urban sprawl	extraction of fish	driver - pressure
land development & urban sprawl	habitat destruction	driver - pressure
land development & urban sprawl	human disturbance to animals	driver - pressure
land development & urban sprawl	hydrocarbons	driver - pressure
land development & urban sprawl	marine debris	driver - pressure
land development & urban sprawl	nutrient input	driver - pressure
land development & urban sprawl	other contaminants	driver - pressure
land development & urban sprawl	pathogens	driver - pressure
land development & urban sprawl	pesticides	driver - pressure
land development & urban sprawl	pharmaceuticals	driver - pressure
land development & urban sprawl	precipitation	driver - pressure
land development & urban sprawl	sediments	driver - pressure
local climate	habitat destruction	driver - pressure
local climate	ocean pH	driver - pressure
local climate	ocean temperature	driver - pressure
local climate	precipitation	driver - pressure

non-commercial fishing	extraction of fish	driver - pressure
non-commercial fishing	habitat destruction	driver - pressure
non-commercial fishing	human disturbance to animals	driver - pressure
non-commercial fishing	marine debris	driver - pressure
ocean dynamics	habitat destruction	driver - pressure
ocean dynamics	human disturbance to animals	driver - pressure
ocean dynamics	nutrient input	driver - pressure
ocean dynamics	ocean pH	driver - pressure
ocean dynamics	ocean temperature	driver - pressure
ocean dynamics	precipitation	driver - pressure
ocean dynamics	sea level rise	driver - pressure
ocean tourism	habitat destruction	driver - pressure
ocean tourism	human disturbance to animals	driver - pressure
ocean tourism	hydrocarbons	driver - pressure
ocean tourism	marine debris	driver - pressure
ocean tourism	other contaminants	driver - pressure
recreational land use	habitat destruction	driver - pressure
recreational land use	human disturbance to animals	driver - pressure
recreational land use	hydrocarbons	driver - pressure
recreational land use	marine debris	driver - pressure
recreational land use	other contaminants	driver - pressure
recreational ocean use	habitat destruction	driver - pressure
recreational ocean use	human disturbance to animals	driver - pressure
recreational ocean use	marine debris	driver - pressure
recreational ocean use	other contaminants	driver - pressure
resorts and golf courses	algal overgrowth	driver - pressure
resorts and golf courses	coral disease	driver - pressure
resorts and golf courses	habitat destruction	driver - pressure
resorts and golf courses	human disturbance to animals	driver - pressure
resorts and golf courses	hydrocarbons	driver - pressure
resorts and golf courses	marine debris	driver - pressure
resorts and golf courses	nutrient input	driver - pressure
resorts and golf courses	other contaminants	driver - pressure
resorts and golf courses	pathogens	driver - pressure
resorts and golf courses	pesticides	driver - pressure
resorts and golf courses	pharmaceuticals	driver - pressure
resorts and golf courses	sediments	driver - pressure
wastewater disposal systems	algal overgrowth	driver - pressure
wastewater disposal systems	coral disease	driver - pressure
wastewater disposal systems	freshwater input	driver - pressure
wastewater disposal systems	habitat destruction	driver - pressure

wastewater disposal systems	human disturbance to animals	driver - pressure
wastewater disposal systems	hydrocarbons	driver - pressure
wastewater disposal systems	non-native invasive species	driver - pressure
wastewater disposal systems	nutrient input	driver - pressure
wastewater disposal systems	ocean pH	driver - pressure
wastewater disposal systems	other contaminants	driver - pressure
wastewater disposal systems	pathogens	driver - pressure
wastewater disposal systems	pesticides	driver - pressure
wastewater disposal systems	pharmaceuticals	driver - pressure
wastewater disposal systems	sediments	driver - pressure
water body	aesthetic environment	state - ecosystem service
water body	aquarium fish	state - ecosystem service
water body	atmospheric regulation	state - ecosystem service
water body	biodiversity	state - ecosystem service
water body	biological interactions	state - ecosystem service
water body	biotechnology resources	state - ecosystem service
water body	climate regulation	state - ecosystem service
water body	coastal protection	state - ecosystem service
water body	education	state - ecosystem service
water body	existence	state - ecosystem service
water body	fish, shellfish, limu	state - ecosystem service
water body	habitat	state - ecosystem service
water body	Hawaiian cultural value	state - ecosystem service
water body	heritage value	state - ecosystem service
water body	inspiration value	state - ecosystem service
water body	medicinal resources	state - ecosystem service
water body	non-extractive recreation	state - ecosystem service
water body	nutrient cycling	state - ecosystem service
water body	scientific research	state - ecosystem service
water body	sense of place	state - ecosystem service
water body	shells	state - ecosystem service
water body	social interaction	state - ecosystem service
water body	spiritual value	state - ecosystem service
water body	transport infrastructure	state - ecosystem service
water body	water purification	state - ecosystem service
water body	anchialine ponds	state - state
water body	beaches	state - state
water body	cetaceans	state - state
water body	corals and hard-bottom	state - state
water body	pelagic fishes	state - state
water body	reef fishes	state - state
water body	turtles	state - state

Appendix D: Management Interview Transcription

Demographic questions:

1. Name: Jamison Gove
2. Number of years studying or living in West Hawaii: 10 years studying Hawaii in general, 2 years of specific west Hawaii research
3. Do you consider yourself: scientist, resource manager, community member, other (specify): scientist

Transcription:

Question 1: Do you agree with the relationships represented in the conceptual ecosystem models?

(Jamison Gove): The CEMs provide important context for viewing the ecosystem. The CEMs make a number of connections within the driver-pressure-state aspect of the model that both validates some of the information we already know about the ecosystem, as well as provide new pathways that we weren't previously considering. For those two reasons, the models are incredibly valuable. The models must be taken with some perspective; some of the pathways, some of the connections between drivers-pressures-state are much more specific, the level of granularity is more specific, where as other pathways are a little bit more scaled back. Meaning that some pathways are vague and some pathways are more specific depending on the given pathway we are talking about. There's varying level of specificity within a given ecosystem model, and that's largely because of the group consensus input. People strongly believe that certain pathways exist, and the more that they know about that information the more information they can give about that pathway. You can't take all pathways as if they are created equal. A specific driver influences a very specific pressure, which definitely has a very specific outcome on a given state. Others (pathways) are, this driver kind of influences this particular pressure, which likely has some impact on the state. And we are going to draw those pathways, but we're not entirely sure exactly how well connected they are. If you look at this 2 dimensional model, you can't take all of the (pathways as) equal, and that's where quantifying the interactions comes into play and we have sort of done that to some extent. That's where that becomes really valuable, because you can treat pathways differently. Also, you would have to sample a ton of people to feel really confident in every pathway you have ever drawn. I think that it's really informative and it helps guide research and guide focus and guides communication between community members, scientists, and managers. That's all super important.

(Rebecca Ingram): So you don't see the uncertainties when you look at a CEM?

(Jamison Gove): Yes. Some pathways are very specific. Some are a bit more broad.

Question 2: The models can be used to determine what component of the ecosystem (e.g., a human-caused pressure) has a relatively large or small impact on other parts of the ecosystem *(e.g., an ecosystem service). Do you think this method of prioritization is useful to management? Why or why not?*

(Jamison Gove): The scoring to me helps elucidate where management can be most effective. The strongest score isn't necessarily where management can actually be effective. It's a prioritization. If in a given ecosystem, a non management pressure, a non management related pressure, so something like wave forcing, is the most important driver of a given ecosystem state, we know that that is unmanageable. Without the scores you can see which are manageable and which are unmanageable, but, as you suggested, you can then sort them, based on strength of interaction. And then figure out, within the given strengths, we can then prioritize. So there's a sorting, and then a prioritization that happens. That helps provide context. So, it's possible that a given human pressure has an influence on an ecosystem state, but it's compared to all the various unmanageable aspects that are driving that state, there's very little we can do to influence that state by changing human actions. (Scoring is) It's a really great way to help provide an ability to rapidly sort and prioritize not only management efforts but also scientific resources. If a given pressure is an environmental pressure, and that's the most important, then we really need to spend some time understanding what that means for the ecosystem state. Because that's part of the management regime; we may not be able to manage it, but we better understand how things are changing and why they are changing, whether that's human related or not. It allows for prioritization but it doesn't necessarily you prioritize what humans are doing, or the strongest interaction. It provides perspective for when you are researching the ecosystem and the decisions you can make with that research. It provides important context. (The scores) move the model from being informative to being directive/allows us to direct efforts.

Question 3: Do you think that this process and visual representation is a useful method for gathering community input?

(Jamison Gove): The process is a good way. I don't know that it is the best way, and it certainly isn't the only way, but it seemed to be effective. It provides a common goal among a diverse group of people that all have interests and understandings and various perspectives of the ecosystem. In that sense, it is a framework that digests all of that nuance, all of that complexity, all of the human nature, all the opinions of people, and I think that's really useful and that's important. The challenge is getting people to show up, and that you have equal representation across the community and other various stakeholders that are involved. I think that the visualization is useful for myself, and other people that are used to representing information in some sort of graphical form (i.e., scientists and managers). It's a great way to visualize information for these people, people who are used to distilling data into a simplistic form. I don't think it's the most effective way to visualize for the community. For individuals who, in their day to day jobs and lives, aren't used to looking at data visualizations. (The visualization) needs to be more common-type images that are representative of a given pressure or driver, and for it to be laid out in a way that is more representative of how these people are actually visualizing the ecosystem. When people visualize their ecosystem and think about what's actually going on, they imagine West Hawaii, their given reef, their given coastline, and that picture is this indelible image in their brain because this is where they've grown up, this is where they live, this is where they exist. So in their mind they can almost feel the environment in which they're talking about. So looking at a flow diagram is almost too sterile, and too detached from the things they're trying to articulate. So I think coming up with something that is a bit more closely aligned with the way many individuals who are providing information are visualizing things would be more appropriate. Especially when talking about getting feedback.

Question 4: One of the goals of this process was to increase communication between multiple stakeholders, incorporating community voices and objectives into important management decisions. Having been a part of the process, do you agree with this?

(Jamison Gove): I don't think there's any doubt that it enhanced communication and collaboration, and connected individuals that would otherwise have not been connected that have common interests in the system, in the area, in the geography. I think if anything, it provided a springboard into follow up communication, into additional group efforts, workshops, or collaborations, as opposed to being all of that in just the workshop / process itself. Although the workshop was really important and it provided good information, I think its real value was connecting the people so that we can continue this process forward. It's really easy to be silo, or to be insulated, to communicate with those individuals that are in your common discipline or interest group and that this workshop, these workshops, the DPSIR process, importantly brings together people from various backgrounds that would otherwise not come together to speak, and to communicate and to try and come to a consensus on what the important aspects of this ecosystems are. That is one of the biggest and most important aspects of the DPSIR process.

Question 5: Overall, do you think that this process was useful for management in West Hawai'i? Why or why not?

(Jamison Gove): The process itself isn't necessarily helping management make decisions, it's helping prioritization, it's helping focus, it's helping parse out different aspects of the ecosystem that need to be better researched or more appropriately understood. Brings to light things that we need to pay attention to. For that, it absolutely helps management. You couldn't just take the conceptual ecosystem process and all of a sudden make a jump to management decisions; it helps guide a scientific and management process. Which is critical, you need to start somewhere. You need a foundational step, and I think this provides a great foundational step. If an entire group of people all have a consensus on a given pressure, such as excess nutrients from a driver which are peoples cesspools, and all of the community is on the same page for that, that provides important foundation for the next steps to make a management decision. We wouldn't have been able to know that that common understanding existed among the community and among the various stakeholders. We didn't know that.

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